DEVELOPMENT OF A “BEST PRACTICE” WORKFLOW FOR THE RAPID BIM VISUALIZATION OF WATER AND WASTEWATER TREATMENT PROJECTS FOR PURSUIT PRESENTATIONS

by

Turner Jackson Cash

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Approved by:

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Dr. Don Chen

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Dr. Yuting Chen

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Dr. Jake Smithwick

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Dr. Stephanie Pilkington

ABSTRACT

TURNER JACKSON CASH. Development of a "Best Practice" Workflow for the Rapid BIM Visualization of Water and Wastewater Treatment Projects for Pursuit Presentations
(Under the direction of DR. DON CHEN)

The overall goal of the research conducted throughout this study was to develop a proposed "best practice" workflow for the rapid development and visualization of BIM models for water and wastewater treatment project pursuits. The success of this project relied heavily on a reduction of time commitment and cost of the production of all necessary visualization deliverable packages for a given pursuit project, while also preserving a desired level of quality. The proposed "best practice" workflow was developed through extensive experimentation with various rapid modeling techniques, visualization processes, and emerging technologies (such as VR and AI image generation models). For evaluation purposes, two case studies were conducted to provide statistical results on the performance of the proposed workflow. It was found that, when compared to traditional workflows, the proposed "best practice" workflow provided a significant reduction to the overall resource requirements of developing deliverables, while also preserving the desired quality. Based on the findings and conclusions of this study, the proposed workflow should be incorporated to improve efficiency of model development and visualization processes for all future pursuit projects.

Keywords: bim, bim modeling, bim visualization, revit, project pursuits, pursuit interviews, engineering marketing, design presentation, design coordination, parametric families, dynamo, parametric modeling, twinmotion, enscape, virtual reality, vr, extended reality, xr, engineering, ai, diffusion

DEDICATION

As I reflect on my academic journey thus far, I envision my knowledge as an ever-growing plant that thrives with the support of various sources. Just as a plant needs a nurturing environment to flourish, someone to plant the seed, consistent care to grow, and a strong support system, my education has been enriched by the guidance and encouragement of those around me.

In order for a plant to thrive, it must be provided with the proper environment for it to do so. This environment can be different for diverse kinds of plants, just as individuals need different environments to encourage their own growth. In my case, I attempted to find a proper environment for myself multiple times before I found the one that suited me the best. UNC Charlotte has provided me with a garden of knowledge that fits me perfectly and a place for my knowledge to grow safely. This environment was curated by the faculty and staff that I encountered throughout my academic journey at UNC Charlotte. In my undergraduate career, this environment was provided by Prof. Wayne Goff, who ensured that the ETCM program was rigorous and provided real world knowledge to his students. Throughout my graduate career, this environment was provided by Dr. Jake Smithwick, who ensured that MSCFE program was flexible for my schedule and was always willing to listen to any ideas or thoughts that I had. Along the way there were also many other professors who enriched my learning experience, especially Dr. Claudia Garrido Martins, Dr. Stephanie Pilkington, and Dr. Yuting “Tina” Chen.

I would be remiss not to mention the individual who planted my seed of interest in BIM, LiDAR, and many of the other topics discussed in this thesis. In my first semester at UNC Charlotte, I met Dr. Glenda Mayo, without whom I would have never developed an interest in these topics. Dr. Mayo had a passion for BIM that was palpable and, through taking her BIM

course, I adopted this same passion. After taking her course, she recommended me for my first undergraduate research position, and I will be forever grateful for that recommendation.

Through this undergraduate research position, I met one of the most important individuals to my academic journey, Dr. Don Chen. Throughout our years of working together on various research projects, Dr. Chen has provided the consistent care and attention needed to grow my knowledge. He has always been a wonderful mentor and has been willing to provide constructive feedback to any idea that I approach him with. Without his guidance and support, I would likely not be writing this thesis. He deserves my full gratitude and highest praise.

Finally, I would like to thank my support system of family and friends for being there for me on the stormiest of days. Without all of your encouragement, I would never have been able to push myself to the levels that I have in order to pursue my education. To my family, who always provided me with love and reassurance when obstacles seemed insurmountable, I could never thank you enough. To my friends, thank you for always providing an outlet for me to decompress and reminding me that it is important to not take life too seriously. I also want to dedicate this paper to my family that has passed on, including my maternal grandparents (Betty Morefield and James "Jack" Morefield), for instilling their homegrown values in me. I hope to honor your memory in every aspect of both my work and my life.

Once again, thank you all for everything that you do. I will be forever grateful for you.

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I also would like to extend my gratitude to my committee members, Dr. Jake Smithwick, Dr. Stephanie Pilkington, and Dr. Yuting "Tina" Chen. It has been wonderful working with all of you and I am honored that you have served on my thesis committee. Your constructive feedback and support has enriched my work and broadened my perspective. Thank you for your support and assistance.

To Dr. Claudia Garrido Martins, thank you for allowing me to practice presenting this material to your BIM students and providing me with a constant outlet for feedback. I am very appreciative of your mentorship and support throughout all of my academic endeavors, from undergraduate capstone to this thesis. Although our paths only crossed briefly, you have made a significant impact on my journey. I hope that our paths will continue to cross throughout my future journeys in academia.

To my colleagues, both at the university and at work, I also want to express my gratitude for supporting me throughout this process. Special thanks to Nicholas Cobler, our conversation about the impacts of AI on the BIM visualization process provided the inspiration for a large section of this thesis. Your mentorship in model visualization also provided me with the base skills needed to complete this research. I also would like to give special thanks to my supervisor, Jason Seagle, who has been extremely supportive of my academic journey and provides a work environment that made it possible for me to complete this thesis while working full time. To the rest of my fellow students and work colleagues, I thank you for the sense of camaraderie and support that you have provided throughout this process.

To my friends and family, thank you for your unwavering love and encouragement. Your belief in me has been a constant source of strength and motivation. I want to specifically mention the following list of family and friends for their love and support throughout this process: Betsy Bumgarner, Neil Cash, Caymen Cash, Abbey Ross, Carl Bumgarner, Allen Morefield, Teresa Morefield, Brenda Turner, Jeanne Hoel, Warren Cash, The Cash Family, The Morefield Family, Maurice Wright, Logan Hundley, Alex Jones, Greg Turpin, Noah Cobbs, and Jamel Chapman.

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Thank you all for being an integral part of this academic journey. I could not have completed this body of work without each and every one of you.

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LIST OF ABBREVIATIONS

Abbreviation	**Definition**
AEC	Architecture, Engineering, Construction
AI	Artificial Intelligence
AR	Augmented Reality
BIM	Building Information Modeling
CAD	Computer Aided Design
DXF	Drawing Exchange Format
EXE	Executable File
GAC	Granular Activated Carbon
HLOD	High Level of Detail
HSPS	High Service Pump Station
KPI	Key Performance Indicator
LAZ	LiDAR Aerial Survey Zip
LiDAR	Light Detection and Ranging
LLM	Large Language Model
LOD	Level of Detail
LLOD	Low Level of Detail
ML	Machine Learning
NLP	Natural Language Prompting/Processing
NOAA	National Oceanic and Atmospheric Administration
PBC	Palm Beach County

bbreviation	Definition
PM	Project Manager
RCP	ReCAP Project
RCS	ReCAP Scan
SLP	Structured Language Prompting/Processing
TOPO	Topography
UI	User Interface
UNCC	University of North Carolina at Charlotte
USGS	United States Geological Survey
VR	Virtual Reality
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant
XR	Extended Reality
3D	Three Dimensional

PREFACE

This Thesis represents the culmination of the research that I have performed over the last year and provides a deep exploration of a subject that I am rather passionate about. This work will explore the potential for increasing efficiency in the workflow of creating model visualizations for pursuit projects through the various techniques available. The main focus of this research is the visualization of water and wastewater treatment project pursuits, although this research could easily be applied to many other types of pursuits. Through extensive research and analysis, I aim to provide a "best practice" workflow that will increase designer efficiency, decrease the time required to create model visualizations, and decrease the capital risk involved with project pursuits.

The concept for this thesis was created out of a need to increase efficiency in an existing model visualization workflow that I utilize on a regular basis. Many project pursuits require these visualizations to be created quickly and with minimal resources in order to decrease the capital risk involved with losing a project pursuit. Although the existing workflow is already relatively efficient, I noticed a few key areas that could be fine-tuned through the use of emerging technologies within industry. A portion of this thesis explores how artificial intelligence can be applied to improve this workflow. The inspiration for this portion of research came from a conversation that I had with a colleague, Nicholas Cobbler, about the implications of AI on the future of model visualizations. During this conversation, we hypothesized that it was extremely important to stay ahead of the curve on AI to ensure that it could be adapted into the visualization workflow without reducing the need for a skilled BIM designer as a "driver" of the process.

This journey has been marked by many challenges and triumphs. I am extremely grateful for my thesis committee (consisting of Dr. Don Chen, Dr. Jake Smithwick, Dr. Stephanie Pilkington, and Dr. Yuting "Tina" Chen) for their constructive feedback and guidance throughout the process of conducting this research. It was their support and encouragement that allowed me to culminate my research into this thesis.

I would also like to like to thank my family, friends, and colleagues that provided me with thoughtful feedback and support throughout the process of writing this paper. Your belief in my abilities and your encouragement is something that I appreciate immensely.

Finally, I want to thank you, the reader, for taking the time to read and explore this body of work. Regardless of whether you read this paper in its entirety or if you are utilizing a portion of it for your own research, I hope you find the information outlined throughout as useful as I did.

This thesis is not only a reflection of the work that I have put forth over the past year, but it is a testament to the support of those around me. I hope that the findings presented in this work will contribute meaningful information into the engineering field and will inspire further exploration into this topic.

Turner Jackson Cash

University of North Carolina at Charlotte

10/5/2024

CHAPTER 1: INTRODUCTION

In the pursuit of large-scale design projects, it is important for companies to set themselves apart from the competition. In an effort to win these projects, companies task marketing teams with the creation of high-level visualizations of the work required to complete the project. These visualizations typically include photo realistic still images, videos, and live demonstrations (i.e., project walkthroughs and virtual reality environments) that represent the work that the company is attempting to procure. The ultimate goal of these visualizations is to convey an elevated level of understanding of the project's desired outcome and to impress the owner during the interview phase of the pursuit. Due to the fact that these are pursuit projects, these visualizations must be created using very general information, must be completed expeditiously, and provide a solid representation of the project's entire scope.

In an attempt to expedite this process, the company's marketing team will work with a Building Information Modeling (BIM) designer in order to develop a basic model for the project. This BIM model can be developed through various programs including Revit, Rhino, SketchUp. An industry standard visualization model must include the following elements: a topographic surface, any existing or proposed structures, any existing or proposed equipment, and the existing surroundings (neighborhoods, bodies of water, etc.). These models are then loaded into 3D Rendering software, such as Enscape, Twin-motion, or Lumion in order to create the desired visualizations.

For pursuit projects these deliverables must be cost-effective, which means that they require tight turnaround times and minimal resource usage, without the sacrifice of quality. Ordinarily, for large-scale design projects these deliverables have a completion timeline of 2-3 weeks (120 hours). This creates an interesting challenge for the BIM designer to create these high-level visualizations in the desired period, with minimal impact to quality or ability to convey the scope of the project. These are the challenges that BIM designers must find solutions to daily, while also managing various obligations to other projects.

1.1 PROBLEM STATEMENT

Traditionally, visualizations for pursuit projects require tight turnaround times and minimal resource usage. With the short turnaround time, these visualizations can require a considerable time commitment and can be costly to develop. With traditional methodology, BIM designers struggle to balance the requirements of these pursuit deadlines and their obligations to other projects. This poses the question, "Through utilization of a new methodology, can the time and resource requirement be reduced, while also maintaining or minimally impacting the quality of these visualizations?"

Through the development of new processes for the creation of high-level visualizations, there is potential to decrease the time requirement and cost of these marketing materials. This would provide an economical solution for the creation of these materials, which would reduce the fiscal impact of pursuit projects. In the world of project procurement, there is always the potential to lose a project and, in turn, all of resources invested in its pursuit. Through reducing the time and monetary commitment required to create these visualizations, it would reduce the company's potential loss. In the event that the project is awarded to the company by the client, this cost reduction also increases the profitability of the project.

The area with the most potential for resource reduction is the modeling process. Every BIM designer has their own methods for developing models in a brief period of time, but it can be difficult to determine what method is actually the best. There are three immediate modeling processes that could see major resource reduction by determining and utilizing the best methodology available: topographic surface generation, equipment family creation, and the development of proposed buildings. The table below includes comparisons between the time requirements for the exiting workflow and the estimated time requirements for the proposed workflow:

Table 1.1.1: Traditional Method Time Req. vs. Proposed Method Time Req. (Preliminary)

Task	Traditional Method	Existing Time Req. (Hours)	Proposed Method	Estimated Time Req. (Hours)
Topographic Surface Generation	Google Earth Method	15-20	CAD Mapper or OpenTopography Method	4-7
Equipment Family Creation	Generic Modeling	5-10	Parametric Modeling	1-5
Proposed Building Modeling	High LOD Modeling W/ Traditional Visualization Techniques	30-40	Lower LOD Modeling W/ Use of AI Visualization Techniques	10-20

The technology used in the creation of these high-level visualizations is constantly evolving and improving, therefore there are many methods to choose from during the process of developing these materials. In the modern design industry, it is important to evaluate the practicality of these emerging technologies to determine which solution is best utilized based on the needs of a specific project. For visualization projects, there are many competing options when it comes to selecting a rapid-visualization program to create high-level renderings of BIM models. These options include, but are not limited to, programs such as Enscape, Twin-motion, and Lumion. Specifically for live VR walkthroughs, programs such as Resolve BIM and Autodesk Workshop XR can be used to quickly create collaborative VR/AR environments for use in model reviews. The advent of Artificial Intelligence, for example EvolveLAB's Veras or

Runway ML, also has interesting implications on the visualization of these projects. The potential for an AI algorithm to create high-level images and video renderings of a project based on an iterative design process is immense. With the evolution of technology, it can be difficult for BIM designers to determine the correct solution based on the project requirements and that is why it is important to analyze each possible solution.

1.2 STATEMENT OF OVERALL PURPOSE

The purpose of this study is to examine various methods of reducing the time and resource requirements of creating high-level visualizations for pursuit projects. This work will focus specifically on Water/Wastewater project pursuits and how to optimize the turnaround time for these visualizations. For comparison, a recent pursuit project, Palm Beach County Water Treatment Plant 2, was used as a project baseline. Using exiting methodology, this project visualization took 118 hours to complete and cost the company approximately $5,005.56. This research utilized multiple case studies to explore the applications of parametric Revit families, Dynamo, and rapid-visualization techniques that are used to expedite the visualization process and reduce cost. The first of these case studies focuses on the difference in the required time commitment, resources, and quality of the Palm Beach County Water Treatment Plant 2 project when utilizing both methods (traditional and new). The second case study utilizes the new methodology developed by this research on a new project, the Concord Hillgrove Water Treatment Plant Granular Activated Carbon Upgrade, and is used to determine the effectiveness of the new workflow on projects of varying scope.

As mentioned, the end goal of this research is to develop a “best practice” methodology for creating visualizations for pursuit projects. This method will focus on the improvement of three modeling processes: topographic surface creation, equipment family creation, and proposed building development.

For many pursuit projects, creating a topographic surface can be challenging because there is extremely limited information available publicly. In order to determine the best process for creating topographic surfaces with limited resources, a few of the most common methods were analyzed. Common methods include the Google Earth mapping method, OpenTopography method, Autodesk Fusion method, and the CAD Mapper method.

The next process with potential for improvement is the procedure of modeling the equipment required for the visualization project. In water treatment projects there are many different pieces of equipment that each plant requires, although many of these are common amongst each water treatment project. In theory, if one could create a library of parametric Revit families, a BIM designer could place the families into the model and fine tune it using the parameters required for the plant. This process could be automated by utilizing a dynamo script with the capability of setting design parameters based on key information provided by the user. This workflow, when compared to existing methods, could drastically decrease the time required to model this equipment.

This research also explored reducing the level of detail requirements to simplify the modeling process of proposed buildings. Many pursuit projects require the preliminary development of new facilities such as administrative buildings, pump stations, and electrical buildings. This process typically includes developing a general facility layout and matching existing “beauty” standards. To improve upon this process, this research analyzed the applications of AI models to rapidly generate visualizations from simplified Revit models. Traditionally, visualizations require a higher level of detail (LOD), but with the advent of new

AI models there is potential to reduce the required LOD while maintaining the quality of the final rendering. This research examined the generation of these AI renderings from models with varying LODs and attempts to determine the best outcomes for different scenarios.

Additionally, this research analyzed various methods of creating high-level visualizations, specifically Enscape and Twin-motion. Utilizing both software packages, the goal would be to develop three key deliverables: a high-level presentation package, a live demonstration, and a VR environment. The deliverables developed in both software packages would then be compared in order to determine the best use for each software. The process of using Autodesk Workshop XR and Resolve BIM for collaborative VR walkthroughs were also examined in order to create an interactive experience for these project pursuit interviews. As stated in previous sections, this research also explored the implications of advanced artificial intelligence, like EvolveLAB's Veras or Runway ML, on the visualization of pursuit projects.

1.3 STATEMENT OF PROJECT SIGNIFICANCE

As stated in previous sections, the goal of this research is to optimize the workflow used to create high-level BIM visualizations by utilizing various time saving techniques. Once developed, this "best practice" workflow provides an opportunity to significantly reduce the cost of creating these preliminary visualizations, while also increasing the quality. This is necessary for pursuit projects because in the event the project is not awarded to the company, it reduces the total financial loss of the company. Conversely, in the event that the project is awarded, the company has a higher potential for profit due to this reduction in cost. The increase in quality also has positive effects on the chances that the company does indeed win the project. This workflow would also reduce the burden on BIM designers who, in many cases, are attempting to balance multiple projects at once. In summary, the "best practice" workflow has promise to reduce costs, improve quality, increase awarded projects, and escalate efficiency of BIM designers.

1.4 DEFINITION OF TERMS

Artificial Intelligence (AI) – Software used to perform tasks or produce output previously thought to require human intelligence, especially by using machine learning to extrapolate from large collections of data **(**Oxford University Press, December 2023).

Augmented Reality (AR) –The integration of digital information with the user's environment in real time. Unlike virtual reality (VR), which creates a totally artificial environment, AR users experience a real-world environment with generated perceptual information overlaid on top of it (Gillis, 2024).

Building Information Modeling (BIM) – The holistic process of creating and managing information for a built asset. Based on an intelligent model and enabled by a cloud platform, BIM integrates structured, multi-disciplinary data to produce a digital representation of an asset across its lifecycle, from planning and design to construction and operations (Autodesk, July 2024).

Extended Reality (XR) – An emerging umbrella term for all the immersive technologies. The ones we already have today in augmented reality (AR), virtual reality (VR), and mixed reality (MR) plus those that are still to be created. All immersive technologies extend the reality we experience by either blending the virtual and “real” worlds or by creating a fully immersive experience (Marr, 2024).

Generative Design – An advanced, algorithm-driven process, sometimes enabled by AI, used to explore a wide array of design possibilities that meet predefined criteria set by engineers or designers (Autodesk, September 2024).

Interoperability – The ability of two or more pieces of equipment or, in this case, software packages, to operate in conjunction (Oxford University Press, July 2023).

Light Detection and Ranging (LiDAR) – A remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances). These light pulses generate precise, three-dimensional information about the shape of a desired object and its surface characteristics. (National Oceanic Atmospheric Administration, 2012)

Machine Learning (ML) – The capacity of computers to learn and adapt without following explicit instructions, by using algorithms and statistical models to analyze and infer from patterns in data; the field of artificial intelligence concerned with this (Oxford University Press, September 2024).

Model Visualization – The creation of 3D renderings, VR environments, etc. from a BIM model for the express purpose of conveying design intent or coordination items to individuals with little engineering knowledge. It can involve the usage of many different methods and software packages.

Natural Language Prompting/Processing (NLP) – Enables computers and digital devices to recognize, understand and generate text and speech by combining computational linguistics, the rule-based modeling of human language, together with statistical modeling, machine learning and deep learning (IBM, 2024).

Parametric Modeling – Parametric modeling is an approach to BIM Modeling in which you capture design intent using features and constraints, and this allows users to automate repetitive changes, such as those found in families of product parts (Brown-Siebenaler, 2024).

Project Pursuit, Pursuit, Pursuit Project – A design project that a design team is attempting to obtain through marketing materials, interviews, and past portfolio. Traditionally, this process is extremely competitive to ensure that the project is awarded to the correct design team.

Rendering or Image Synthesis – A representation of a building, interior, etc., executed in perspective and usually done for purposes of presentation (Dictionary.com, n.d.).

Stable Diffusion – A generative artificial intelligence (generative AI) model that produces unique photorealistic images from text and image prompts (AWS, 2024).

Structured Language Prompting (SLP) – A form of prompting that involves carefully programming instructions, examples, and constraints to make large language models handle challenging objectives predictably. This approach translates human knowledge into a prompt "script" that trains the AI system to execute a desired flow based on inputs (Ramlochan, 2024).

Virtual Reality (VR) – The use of computer modeling and simulation that enables a person to interact with an artificial three-dimensional (3-D) visual or other sensory environment[s]. VR applications immerse the user in a computer-generated environment that simulates reality through the use of interactive devices, which send and receive information and are worn as goggles, headsets, gloves, or body suits (Lowood, 2024).

1.5 ASSUMPTIONS, LIMITATIONS, AND DELIMITATIONS

Due to the scope of this research, it is important to recognize any potential restrictions that may impact the study. Being that this thesis research is a requirement to complete my master's program, there is an inherent time constraint that necessitates an extremely focused scope. In order to maintain this focus, many assumptions, limitations, and delimitations have been placed on this study. The following subsections will address and explain each assumption, limitation, and delimitation that has been placed on this study.

Assumptions

While conducting the study presented in this work, a few assumptions were made regarding the research methodology and data collected. As with any research paper, it is important to acknowledge these assumptions and ensure that the reader is aware of them. Many of these assumptions arise from a need to limit the scope of the study, while also ensuring that the research conducted is accurate and valid.

While there has been an express effort to avoid bias while conducting this study, there is the inevitable fact that the researcher's perspective will influence the research posed in this work. Due to the fact that the creation of a research methodology and data interpretation was solely the responsibility of a single researcher, it can be assumed that the findings will reflect the perspective of the researcher, and that the data could be interpreted differently by another party. This should not influence the validity of the study, as most research is inherently a product of the researcher's perspective and experience within industry. While this paper will provide discussion and interpretation of the data, an effort will be made to present the data in a way that will allow the reader to interpret it in their own perspective.

It is also important to acknowledge the assumption that the findings of this study have an inherent generalizability and can be applied to a broad range of topics. While the focus of this study is improving a specific workflow for the creation of model visualizations for water and wastewater treatment project pursuits, there is an assumption that the many segments of this study can be utilized to improve workflows for the various processes presented throughout this work or that fragments of this research can be used in other capacities. The reader should keep this in mind throughout the examination of this study, as the intent of this research is to optimize many common tasks in creating BIM models, visualizing these models, and presenting these visualizations to parties of interest.

It is also important to acknowledge that this thesis contains forward-looking statements regarding the assumed futures of technologies and innovations discussed throughout. These statements are based on industry wide expectations and involve uncertainties that could cause the actual futures of these technologies to differ. The portions of this study that contain forward-looking statements and projections could create future inaccuracies in this research. It is highly recommended that future researchers keep this in mind throughout reviewing this work and cross verify these statements with future research into these topics.

This study also assumes that the BIM designers that utilize the proposed "best practice" workflow are experienced Revit users. Many of the completion times provided throughout this study are based on a BIM designer with 4 years of experience utilizing Revit for approximately 40 hours a week. In the event that the BIM designer utilizing the proposed workflow is not experienced in Revit, the completion times presented in this work will likely not be reflective of the results achieved by the user.

Finally, it is assumed that the case studies represent valid and reliable proof of the improved workflow. By conducting case studies on two projects of varying scope and reviewing the data collected on the workflow, it is assumed that this will provide significant evidence to support the hypothesis of this research. The data gathered from each case study will represent two different scenarios of varying complexity to test the workflow in different situations. It can be assumed that, by conducting both case studies, it will prove the effectiveness of the proposed workflow in each situation. By assuming this information, it allows the researcher to make a broad assumption that the workflow will be effective in similar situations.

Limitations

Whilst developing the scope of this study, it became apparent that there are some minor limitations that must be addressed. These limitations arise from the fact that visualization of BIM models for project pursuits is a relatively new phenomenon and that this study relies heavily on emerging technologies.

One of the largest limitations of this study is the lack of past studies regarding improving the workflow of creating BIM visualizations. Upon initial research of this topic, it became clear that there is only a small quantity of past studies that directly addressed the questions posed in this thesis. Nonetheless, there are many studies regarding the visualization of BIM models, generative design, dynamo, and parametric families that can be utilized to support this study. By utilizing these existing studies, the impact of this limitation on this study should be minimized.

Another limitation of this research is the heavy reliance on emerging technologies, specifically artificial intelligence and generative design. While there is a vast library of research on both topics, it seems that both technologies are evolving at a pace that can quickly render previous research impertinent. In order to best negate this limitation, this study will attempt to only utilize pertinent and recent research studies on these topics in order to ensure that the background information used has the upmost accuracy. It is also important to consider that the sections that focus on these technologies will likely become snapshots of the year in which this research was conducted as this technology continues to evolve.

Delimitations

Throughout the process of developing the scope of this study, decisions were made on the delimitations of the study. The delimitations of this study originate from an attempt to avoid scope creep due to the timeline requirement of the project. By placing these delimitations on the project there is hope that they will have a limited impact on the value of this research, while also creating an unattainable time requirement.

The first delimitation is that this study will not address improving methods for creating background imagery for visualization projects. While this process can be time consuming, pursuit projects typically require extremely basic background elements and there are already certain methods utilized to reduce the time requirement. These methods include reducing the level of detail (LOD) as elements become farther away and duplicating elements in order to fill in blank space. For example, a BIM designer may only model three house types and duplicate them in order to create a full neighborhood.

The second delimitation of the study is that it will only focus on common equipment types when creating the library of parametric families. Although these parametric families will save time after their creation, they are very time consuming to create. Therefore, the goal of this research is to focus on creating parametric families of the most common equipment types in order to avoid scope creep. Specialized equipment can also vary vastly depending on the requirements of the project. The idea is that it would be more time effective to model basic versions of this specialized equipment or request families from the manufacturer in order to complete these visualization projects.

The third delimitation of the study is that it will not examine a new methodology for the rapid generation of existing buildings. This is because existing buildings are already relatively easy to model using the existing methods and there is little potential for time reduction. Many pursuit projects only require a basic “shell” model, which represents the exterior of the building. The idea behind this is that, barring any work being performed inside of an existing facility, the client already knows the interior of their own facility and any attempt to visualize it is redundant.

1.6 CONCLUSION

In conclusion, the ultimate goal of this research is to provide a "best practice" workflow for the rapid visualization of water and wastewater treatment models for project pursuit interviews. This research will aim to reduce the time required to create these visualizations by examining the multiple methods for topographic surface creation, equipment family creation, development of proposed buildings, and rapid creation of visualization deliverables. Through reducing the time required to create these models and visualizations, it can reduce the capital risk of pursuing a design project and increasing the potential profit of a successfully procured project. This project will be considered successful if the proposed workflow provides a promising reduction of the time required to create these visualizations, while having a negligible impact on quality. This research was applied to two case studies in order to provide tangible results and proof that the workflow can be applied to projects of varying scope. While the main focus of this research is on water and wastewater treatment projects, this research should be applicable to multiple types of design projects and should provide readers with a broad outline of how to apply the workflow for their own purposes.

CHAPTER 2: LITERATURE REVIEW

While there is not a vast catalogue of specific literature available for the creation of high-level BIM visualizations for design projects, it is still critical to explore the available literature on applicable topics. Much of the academic literature reviewed in the following section was sourced through Google Scholar or UNCC's vast library of databases. In an effort to aid this study, the literature review includes many articles focused on the common themes of BIM, parametric modeling, generative design, visualization, virtual/augmented/extended reality, artificial intelligence models, and project marketing principles. This section will first outline these common themes and provide useful information that was uncovered by conducting a review of the pertinent literature. While these common themes are broad, the information within the reviewed literature provided a solid foundation for this study. For ease of reading, this section will also conclude with a summary that synthesizes the main ideas of each common theme.

2.1 COMMON THEMES

BIM as a Multi-level Coordination Tool

As technology improves, Building Information Modeling (BIM) is becoming more effective as a tool for communicating complex designs between designers, engineers, contractors, and clients. According to many studies, BIM helps bridge the gap between designers and their clients by providing an easily understood representation of the end product. Welin Shen stated, "Apart from its advantages in enhancing designer's efficiency, [BIM] also provides a platform facilitating the understanding of complex building by inexperienced clients due to its 3D virtual reality representation of the final built environment" (Shen, 2011). One study follows the Grangegorman Development Project, which had the goal of consolidating all 39 locations of the

Dublin Institute of Technology onto one campus. This project chose to only utilize BIM as a coordination tool during the post-tender phase of the project but faced many coordination issues during the pre-tender phase. The aim of this study was to prove the significance of utilizing BIM for designer-user communication during the pre-tender stages of a project. The study suggests "that the application of BIM can serve as an enhanced communication tool to improve relations between the design team and the end-user" (Mcauley et al, 2015). This idea is also supported by Lin et al. (2024), which stated that by utilizing a rendered BIM model "the building can be shown to people who are not familiar with the project, and the design concept can be conveyed easily so that the people have a better understanding of the building."

Interoperability of BIM, Virtual Reality, and Rendering Software

In recent years, many BIM software packages have developed interoperability with rendering engines that are used to create high-level visualizations. Borkowski & Nowakowski (2023) conducted research that provided an overview of various real-time rendering engines that had interoperability with BIM software packages. The goal of this research was to determine the "best use" case for each engine, compare their prices, and provide a deeper understanding of how these engines can provide value to design projects. Borkowski & Nowakowski (2023) concluded that "The advantages of real-time rendering engines are the speed of editing and the ability to observe changes synchronously." Many of these rendering engines have VR applications as well, which provides interesting opportunities for utilizing this technology throughout the design process. Ehab et al. (2023) states that "The integration of VR plugins within BIM systems offers numerous advantages for architecture and urban design projects. These advantages include immersive and realistic visualizations, improved communication, and fostering collaboration among professionals and stakeholders." These studies support the hypothesis of the proposed research that rapid visualization software packages are useful tools for the quick creation of high-level visualizations of BIM models.

Generative Design & Parametric Modeling in Revit

Revit gives users the ability to create families with variable parameters, known as parametric families, in order to expedite the modeling process. By setting the parameters of these families, users can quickly update the dimensions of the modeled element. As a basic example, a box could be modeled with width, length, and height parameters in order to rapidly change the dimensions of the box. Sabahi (2010) examined the effectiveness of parametric families in expediting the process of modeling temporary structures, specifically formwork and shoring systems. This study concluded that utilizing parametric families does indeed save time and reduce the effort required to create these elements. In order to automate the parametric modeling process, Dynamo can be leveraged in order to automatically assign parameters to these families based on various forms of user input. In a study, Lee et al. (2023) proposed a framework for semi-automating 3D as-built modeling using parametric families. This framework pulled parameters from LiDAR point clouds and utilized a dynamo script to assign these values to corresponding parametric families before placing them. This allowed for the generative design of 3D structures utilizing data gathered from LiDAR scans. While this framework is slightly advanced for the scope of this project, elements of it can be borrowed in order to achieve the goals of the proposed research.

Outlook on Using AI for Visualization

While there is not significant research on the application of Artificial Intelligence video generation in AEC (architectural, engineering, and construction) field, it is important to analyze its potential. With the advent of this recent technology, it is necessary to understand if it is a viable option for BIM designers. According to a study by Karaarslan & Aydin (2024), "Text-to-video AI has the potential to revolutionize various creative sectors, including filmmaking, advertising, graphic design, and game development, as well as industries such as social media, influencer marketing, and educational technology." Liu et al. (2024) concludes that "by providing a tool that can simulate realistic environments and scenarios, Sora offers a powerful solution for visual storytelling… Sora's potential to revolutionize content creation across marketing, journalism, and entertainment is immense." The findings of these studies also extend to the AEC industry, especially regarding pre-design marketing for pursuit projects. In theory, basic design criteria could be input into a diffusion model, such as EvolveLAB's Veras or Runway ML, to rapidly develop a rendering of a preliminary design project.

Stable Diffusion: Text to Image Deep-Learning Model

Stable Diffusion is an AI diffusion model that can be used to effectively generate images based on text prompts. In regard to this study, Stable Diffusion is the main AI model used by one of the text-to-image AI platforms, EvolveLAB's Veras, that is being used to generate high-level visualization of Revit models. According to Borji (2023), Stable Diffusion "is primarily used to generate detailed images conditioned on text descriptions. It can also be applied to other tasks such as inpainting, outpainting, and image translation. This model is trained on 512 x 512 images from a subset of the LAION-5B database. It uses frozen CLIP ViT-L/14 text encoder to condition the model on text prompts. With its 860M UNet and 123M test encoder, the model is relatively lightweight and runs on a GPU with at least 10GB VRAM." Based on this description of Stable Diffusion, it can be understood why that EvolveLAB's Revit plugin utilizes this model in order to create detailed renderings of Revit models. While that image generation can be resource intensive, it seems that Stable Diffusion offers a lightweight alternative which will allow it to run in conjunction with other high intensity processes. In his paper exploring the applications of the Stable Diffusion Model, Lei (2023) concludes that “The stable diffusion model shows a potential for application in image synthesis tasks. For example, images with realism and diversity can be gradually synthesized by performing the diffusion process on noisy images. The stable diffusion model can generate images with different styles, textures, and structures by controlling the parameters and steps of the diffusion process, and the results are relatively stable in detail and quality.” Therefore, based on Lei’s conclusions, it can be ascertained that, while it may be a trial-and-error process, stable diffusion can consistently produce high fidelity images based on a given set of parameters.

Runway ML’s Gen-3 Alpha Diffusion Model

Another diffusion model that is highly examined during the course of this research study is Runway ML’s Gen-3 Alpha. This model is at the core of Runway ML’s image-to-video platform. Although there is not much research into Gen-3 Alpha, there are still valuable pieces of literature that can be reviewed to aid in the understanding of how that the model can be utilized. In a blog post, Vrtaric (2024) defines Gen-3 Alpha and examines the possible use cases in image-to-video generation. According to Vrtaric (2024), “This advanced model… produces high-resolution, detailed, and consistent videos with impressive speed and precision. The model’s ability to generate high-quality videos from simple prompts showcases its potential for creative flexibility.” This statement reinforces the hypothesis that Runway ML’s Gen-3 Alpha can aid in the visualization of engineering design projects. The creative flexibility that is provided by this model, in theory, can allow BIM designers to rapidly create video walkthroughs of models and can support the creation of multiple variations of a given design. While attending Autodesk University 2024, I had the chance to speak with the creators of EvolveLAB’s Veras. In our conversation regarding image-to-video workflows, they revealed that Runway ML's Gen-3 Alpha, when used in conjunction with Veras, can be extremely effective at generating video walkthroughs of BIM models. This revelation provided the inspiration for the proposed text-to-image-to-video workflow that is presented in this study.

Prompt Engineering: Natural Language and Structured Language Prompting

In the world of AI, it is important to consider how to effectively communicate with a given model in order to receive the desired results. Prompt Engineering is a new concept that focuses on choosing effective communication strategies for each type of AI model. In order to effectively engineer AI prompts, it is necessary to understand the different languages that AI models can speak. One such language is Natural Language Prompting (NLP), which can recognize the complexity of normal conversational language. Models that utilize NLP do not require specific formatting for prompts and are much easier for a layperson to utilize. This claim is backed up by Cain (2023), who states that "LLM AI [Large Language Model Artificial Intelligence] tools, including ChatGPT, are designed to comprehend and generate human language through text-based user interfaces. This means LLM AI end-users do not require advanced or specialized coding skills to interact with these tools." Unfortunately, as this study is being conducted, most of the models being examined in this study utilize a different language called Structured Language Prompting (SLP). In SLP models, the user must strategically craft articulate prompts in order to achieve the desired outcome. These models do not understand conversational language and are programed to only recognize structured prompts. Ramlochan (2024) states that "Structured prompting involves carefully programming instructions, examples, and constraints to make large language models handle challenging objectives predictably. This approach translates human knowledge into a prompt "script" that trains the AI system to execute a desired flow based on inputs." In essence, while these prompts take time and skill to construct, there is the added benefit that these models typically produce results faster and with greater accuracy.

Effective Marketing Principles for Design Projects

At its core, this study revolves around creating effective marketing materials for multi-discipline engineering design projects. Whilst conducting this study, it is important to consider the effective marketing principles utilized by those within the AEC industry and how this study can be utilized in concurrence with these principles. In a study conducted by Huff (1984), 103 small civil engineering firms were surveyed in order to get a sense of their attitude towards marketing in the industry and what principles they believed worked best. According to Huff (1984), "Only slightly over half agreed with the statement that 'In obtaining clients, it is more important who you know that what you can do'; 38% disagreed, compared with 97% agreement with the statement concerning the importance of the quality of the firm's work and its reputation." Based on these findings, it can be concluded that some of the most crucial factors in effectively marketing a design project include both the quality of a firm's work and its reputation. While the work presented in this thesis is unrelated to the reputation of a company, the visualizations created in this project can be used to bolster the quality of a firm's work and show that they have done their due diligence in developing pursuit materials, thus aiding their marketing strategy. In another journal article, Schaufelberger (2000) states that "Owners are [becoming] more sophisticated and demanding high-quality professional presentations from the prospective delivery team." This statement reflects my own professional experience with the owners of Water and Wastewater Treatment Plants. Through leveraging the best-practice workflow proposed in this thesis, it will allow for the creation of these desired high-quality presentations by providing the pursuit team with high-level visualizations of the project that they are attempting to procure.

2.2 SUMMARY

To summarize, the following claims have been supported according to the review of published literature related to the research questions posed in this study:

I. BIM is an effective tool for communicating complex designs amongst designers, engineers, contractors, and clients.

II. The interoperability of various BIM, virtual reality, and rendering software packages can champion the rapid creation of high-level presentation materials.

III. By utilizing generative design & parametric modeling, BIM designers can reduce the amount of time required to develop 3D models.

IV. Generative design & parametric modeling can be utilized to semi-automate many tedious modeling processes.

V. Text-to-video Artificial Intelligence, such as EvolveLAB's Veras or Runway ML, has the potential to aid in the rapid development of base-level walkthroughs.

VI. While it may be a trial-and-error process, stable diffusion can consistently produce high fidelity images based on a given set of parameters.

VII. The creative flexibility that is provided by Runway ML's Gen-3 Alpha, in theory, can allow BIM designers to rapidly create video walkthroughs of models and can support the creation of multiple variations of a given design.

VIII. While Structured Language Prompts (SLPs) take time and skill to construct, there is the added benefit that models which utilize SLPs typically produce results faster and with greater accuracy.

IX. Some of the most crucial factors in effectively marketing a design project include both the quality of a firm's work and its reputation.

CHAPTER 3: METHODOLOGY

As stated in prior sections, the aim of this study is to improve upon existing workflows in visualization model creation, model visualization, and project pursuit presentations. Success of this research will rely heavily on reducing the time requirement of producing effective visualizations of BIM models, while also maintaining the same level of quality. This section provides an overview of the research methodology utilized in order to answer the research questions being posed. The methodology is designed to collect both quantitative (time & cost) and qualitative (quality) data regarding the many processes that are the focus of this study. The study determines a “best practice” workflow for creating project pursuit visualizations for water and wastewater treatment projects through data collected on many methods of model development, model visualization, and presentation. After the “best practice” workflow is determined, it will be put to the test on two projects of varying scope in order to prove its effectiveness. The first case study will focus on a previous pursuit project, Palm Beach County Water Treatment Plant 2, which will represent the workflow’s effectiveness on a large-scale water treatment plant upgrade. The new workflow will be applied based on the same project constraints, and the resulting deliverables will be compared to the original deliverables that were developed using traditional methods. This will provide both qualitative and quantitative data that will be pivotal to proving the effectiveness of the “best practice” workflow. The second case study will apply the new workflow to a smaller scale water treatment project pursuit, Concord Hillgrove Water Treatment Plant GAC Upgrade. This project will offer data on the effectiveness of the workflow on a small-scale project and will aim to compare completion time of the project to the previously estimated time requirement (original estimate developed based on traditional workflow).

3.1 RESEARCH QUESTIONS

In this study, there are six key research questions that will be answered through previous research and direct applications. The aim of this section is to identify and provide the necessary background information for each research question. By answering the following questions, it will allow the researcher to determine a "best practice" workflow for creating visualization models, developing model visualizations, and presenting these visualizations to project stakeholders.

What is the most effective method for topographic surface creation?

One of the most imperative tasks for developing visualization models is the creation of a topographic surface to be used as a base for the model. In the past, designers would have to use very limited information to craft a generic topographic surface. One common method that designers have used is the Google Earth method. In this method, designers must manually pull elevation data from Google Earth and translate this information to Revit in order to create the topographic surface. While this traditional method gives the designer express control over the final topographic surface, it has several identifiable issues. The major issues with this method are the tedious nature of manually translating the elevation data to Revit, the immense time requirement, and the reliance on skilled designers to ensure accuracy. This research will explore two possible methods for improving this process: The LiDAR method and The CAD Mapper method. Both of these methods involve obtaining public access topographic data and then importing this information into Revit. The key differences between these methods is the type of data being imported into Revit and the process for importing this data. For the LiDAR method, a public domain service called OpenTopography will be utilized to obtain LiDAR collected by United States Geological Survey (USGS) and the National Oceanic and Atmospheric Association (NOAA). This point cloud data will then be imported into Revit and an add-in called

Scan Terrain will be used to generate a topographic surface. For the CAD Mapper method, a AutoCAD file will be generated from an online tool called CAD Mapper. This file will then be imported into Revit and will be used to generate a topographic surface. Once this process has been completed, the results of each method will be reviewed in order to determine which method will be used in the proposed "best practice" workflow.

Is it beneficial to develop parametric families and dynamo scripts for the purpose of creating visualization models?

While developing visualization models for water and wastewater projects, it is typical to have various pieces of equipment that must be modeled. The traditional workflow requires BIM designers to develop simplified families of each piece of equipment that can be inserted into the model. Due to the usage of simplified families, it is challenging to rapidly adjust the equipment if needed and this can lead to issues later in the process. For instance, if a simple family is created for a chemical tank and it is later determined that this tank is too small, the tank cannot be easily resized to reflect the intent of the proposed work. The rapid development of these simple families also relies heavily on the skill of the BIM designer tasked with developing the model. If a designer does not have experience in rapidly developing these simple families, the time required to create them can grow exponentially. This research will explore the development of parametric families for required equipment and the creation of dynamo scripts to rapidly edit these parameters. Through replacing simple families with parametric families, a single family can be used to model various sizes of a given type of equipment. The developed dynamo scripts will allow BIM designers with less experience to rapidly edit these pieces of equipment through an intuitive UI (User Interface), which will aim to increase the ability of these designers to develop visualization models. This workflow has the potential to decrease the time required to model both existing and proposed equipment in visualization models. The aim of this research question is to determine whether the availability of a library of parametric equipment families and dynamo scripts reduces the time requirement enough to justify the effort required to create this library.

Does AI create opportunities to reduce the required time commitment of visualizing proposed structures?

As artificial intelligence evolves, there has been an increase in the utilization of AI tools in order to rapidly create stunning images based on given prompts. In light of this trend, EvolveLAB has developed a Revit plug-in, Veras, that utilizes the stable diffusion model to aid BIM designers in developing visualizations of their models. Through traditional visualization workflows (Enscape or Twinmotion), the LOD (level of detail) drives the quality of the final product. For example, a model with a lower LOD produces a visualization of a lower quality and a model with a higher LOD will produce a visualization of a higher quality. This research will aim to challenge this idea by utilizing Veras to visualize models of varying LODs and comparing the quality of each product. Specifically, this portion of research will focus on reducing the time requirement of visualizing the exteriors of proposed structures. Through utilizing Veras, it could allow designers to reduce the LOD on proposed structures, while maintaining the desired quality of the visualization. If this process proves effective, it could be applied to the "best practice" workflow developed through this research.

Enscape vs. Twinmotion: What are the specific use cases for each rapid visualization program?

A key element of creating an effective model visualization is the selection of the correct rapid visualization program. While there are many of these programs available, this research will focus on two of the most commonly used programs: Enscape and Twinmotion. Typically, designers would select one of these programs and utilize it to create all of their visualization deliverables. In this research, the applications of both programs will be explored, and the best use cases will be determined for each. Through this process, it will be determined which program is best for developing each of the following deliverables: rendered images, rendered cross-sections, rendered videos, VR environments, and live-model walkthroughs. The ultimate goal would be to determine if only a single program or a combination of both programs should be utilized for the creation of these pursuit deliverables in order to provide the best quality.

Are Autodesk XR Workshop and Resolve BIM viable options for creating interactive project walkthroughs for pursuit interviews?

In recent years, there has been a major push to incorporate VR, AR, and XR technology into the design industry. Typically, these technologies are reserved for the design stages of a project and are only utilized amongst the design team. Despite the rapid growth of this technology, there is still a large amount of skepticism surrounding the use of these technologies and some individuals within the industry view it as a gimmick. Many of the concerns surrounding this technology are related to VR sickness and the large-scale implementation of technology across a company. Autodesk XR workshop and Resolve BIM have developed platforms that consider these concerns and offer viable solutions. Both of these have user friendly movement methods that reduce the likelihood of VR sickness and incorporate directly into ACC (Autodesk Construction Cloud) which a majority of companies utilize to host their models. With these concerns addressed, it is intriguing to explore the implications of these technologies on project pursuit interviews. Theoretically, by utilizing these technologies, pursuit interviews could be developed in an interactive manner and could be hosted in a live-virtual reality environment.

This would give companies that adopt these technologies a "wow" factor and could potentially increase the amount of pursuit projects being won.

Do image-to-image and image-to-video AI programs have a viable application for creating model visualizations?

With the advent of image-to-image and image-to-video AI programs, such as EvolveLAB's Veras or Runway ML, there has been a major increase in the utilization of AI in creating high-level visualizations. Based on conversations with the EvolveLAB team at Autodesk University 2024, their team has explored the implications of using Runway ML to create videos from the images created in Veras. This idea also has intriguing implications on the process of visualizing models for pursuit projects, as this could reduce the time requirement of creating these high-level image and video visualizations through reducing the necessary LOD. By reducing the required LOD, and in-turn the time requirement, there is potential for BIM designers to rapidly develop multiple iterations of a proposed design and select the one that best suits the stakeholders' needs. This research will examine the application of these AI models and determine whether they offer a viable solution for creating both stunning visual images and videos for water and wastewater pursuit projects specifically.

3.2 DEVELOPMENT OF A WORKFLOW

In developing a "best practice" workflow, it is important to consider the various options available for improving key areas of the existing workflow. In the following pages, a detailed overview of the methods used in the "best practice" workflow will be provided. This overview will not only provide the experimental process for selecting the best method for each key process, but it will also provide justification for why the selected method is best suited for the proposed workflow. In the event that there are multiple methodologies being considered, some key considerations for the selection process are the reduction of time requirement, cost of the tools used, and ease of use. Through applying these key considerations in situations where two methodologies produce similar results, this will allow the researcher to easily select the method that best suits the proposed workflow. This overview will conclude with an outline of the proposed “best practice” workflow and will supply readers with specific use cases for the various tools examined in this study.

3.2.1 TOPOGRAPHIC SURFACE GENERATION

One of the first key areas for improvement that was identified at the onset of this study was the process for generating topographic surfaces to allow for the visualization of the exiting grade on a given site. The current accepted workflow requires BIM designers to extract the available elevation information from Google Earth and then translate this information into Revit. This process is extremely tedious, time-consuming, and produces a mediocre final product. Unfortunately, due to these factors, many designers choose to develop visualization models on flat topographic surfaces that do not represent the actual site conditions. This not only affects the overall quality of the model, but it also affects the client’s instant recognition of their own site, which in turn reduces the overall effectiveness of the visualization model. These factors necessitate the development of a new and improved method for topographic surface generation. There are two promising methods that could instantly improve the process of developing topographic surfaces for visualization models: The LiDAR Method and The CAD Mapper Method. These methods have the potential to reduce the modeling time required, improve accuracy of the surface, and eliminate the tedious nature of crafting these surfaces. This section will outline all of the methods mentioned above, provide insight into the selection process, and then culminate with the selection of the best method for the purpose of this study. For the sake of comparison, all three methods will be utilized to develop topographic surfaces for both the PBC WTP 2 and the Concord Hillgrove WTP projects.

Existing Workflow: The Google Earth Method

As mentioned previously, the existing workflow used to generate topographic surfaces for visualization models is the Google Earth Method. This workflow has become commonly utilized due to the complete control over the final surface given to the designer, the fact that the surface is built entirely in Revit, and the ease of making edits to the surface after initial completion. The workflow also has many innate flaws that produce the need for a better process. These flaws include the extremely tedious process, the high skill level required to create the surface, the reliance on questionable elevation data, and the high potential for loss of work during the modeling process. Over the course of the next few pages, this process will be laid out in a step-by-step manner and will allow readers to gain insight into exactly how this method is utilized. The process is as follows:

- *Step #1:* When developing a topographic surface using the traditional Google Earth Method, the first step is to locate the project site on Google Earth Pro. It is also essential to have both the "3D Buildings" and "Terrain" settings toggled on.

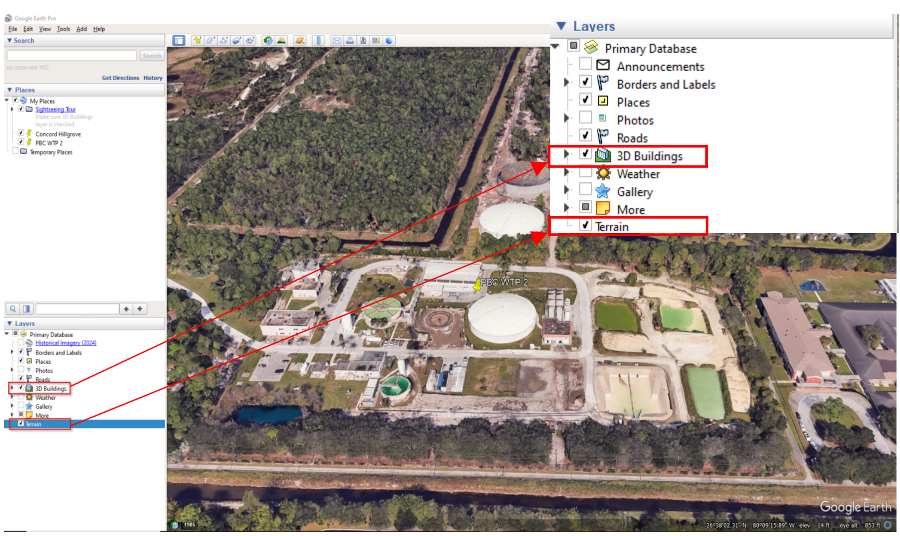

Figure 3.2.1.1: Google Earth Pro View of PBC WTP 2 Showing Appropriate Settings

- *Step #2:* The BIM designer would then orient the view into an overall site view, create a measurement for scaling purposes, and then screenshot the Google Earth Pro window. It is best to create a longer measurement to ensure that it can be easily identified in the screenshot.

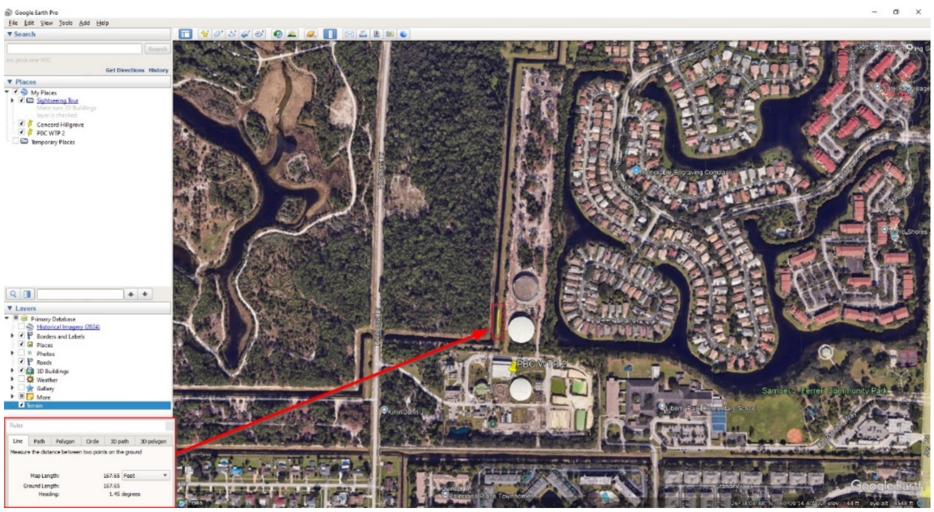

Figure 3.2.1.2: Screenshot of Google Earth Pro with Measurement for Scaling Purposes

- *Step #3:* After capturing the screenshot, open Revit and create a plan view at elevation 0.00. In this plan view, insert the screenshot and use the measurement to scale the image.

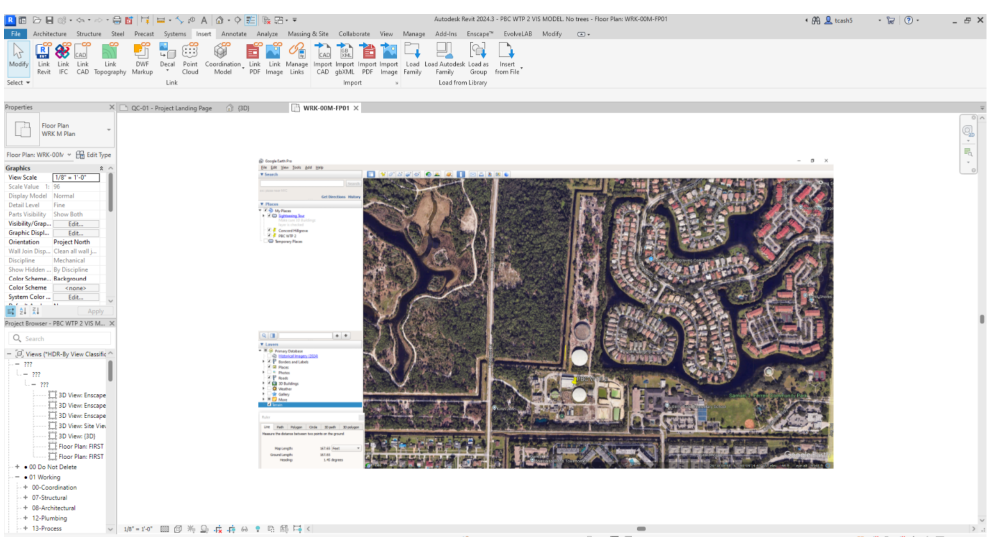

Figure 3.2.1.3: Image of Screenshot Imported into Revit at Elevation 0.00 and Scaled.

- *Step #4:* Under Revit's Massing & Site Tools, use the "Toposolid" tool to create a topo solid from a sketch. After selecting this option, draw a "boundary line" around the desired site and create the Toposolid. This process will create a flat Toposolid that encompasses the entirety of the specified boundary. For the purposes of this study, it will be assumed that all Toposolid types created consist of a 4" thick layer of grass on top of 100' thick layer of soil.

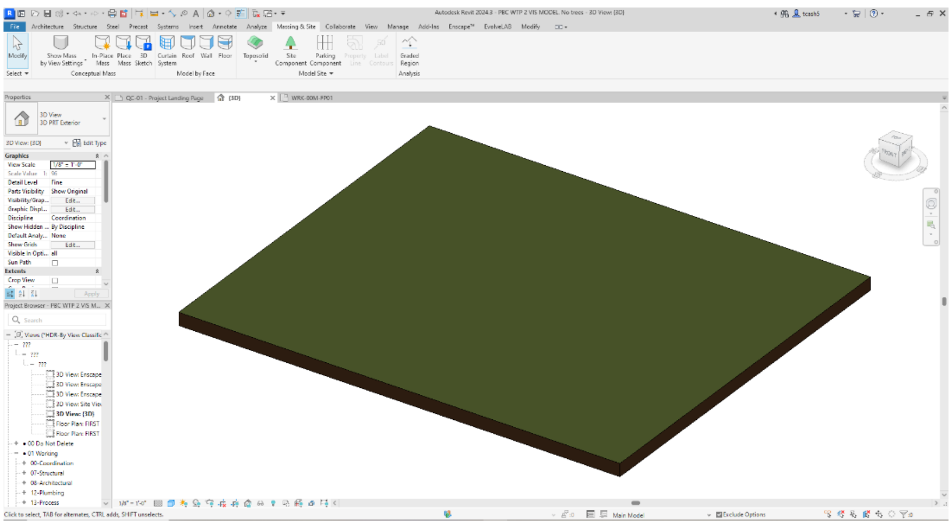

Figure 3.2.1.4: Toposolid Created Using the "Toposolid" Tool and Specified Boundary

- *Step #5:* Select the Toposolid and then select the "Modify Sub Elements" tool. In the plan view that was created during step 3, begin translating the elevation information from Google Earth Pro. In Google Earth Pro, the spot elevation at the location of the cursor is provided in the lower right-hand corner of the window. Through this process, the designer must create hundreds, if not thousands, of points on the Toposolid based on the spot elevations pulled from Google Earth Pro.

Figure 3.2.1.5: Image Showing a Spot Elevation of 16FT in Google Earth Pro

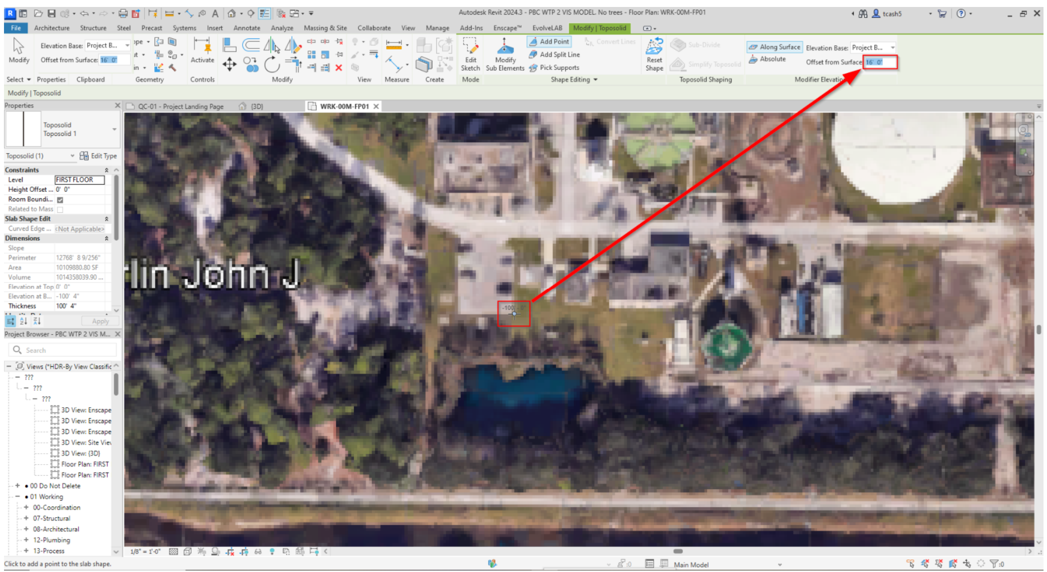

Figure 3.2.1.6: Image Showing the Creation of a Point at an Elevation of 16FT

- *Step #6:* After translating as much elevation information as possible to the Toposolid, the process of generating a topographic surface is complete and the surface is ready for the creation of features such as roads, waterways, building pads, sidewalks, etc. using traditional methods.

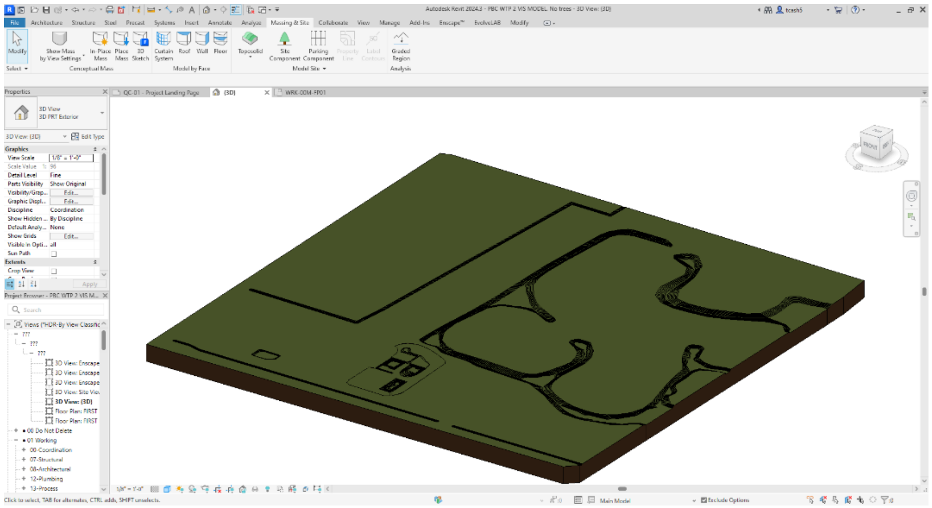

Figure 3.2.1.7: Toposolid Completed Using Google Earth Method

Proposed Workflow #1: The LiDAR Method

The first workflow being examined as a potential replacement for the existing workflow, is the LiDAR method for topographic surface generation. In this method, open-source LiDAR data sets are accessed through a website called *OpenTopography* (https://opentopography.org/) and a Revit plug-in called *Scan Terrain* is used to rapidly generate a topographic surface. The data sets available on this site are collected by various surveying and data collection organizations. Specifically, in regard to this study, USGS and NOAA data sets have been utilized. There are many potential positive impacts to utilizing this method that include the generation of a survey grade topographic surface, the free usage of all of the tools involved (regardless of site size), and the fact that the generated point cloud can also be used to aid in existing modeling efforts. While this method offers many positive impacts, it is also paramount to consider the potential downsides of using this method. With the usage of LiDAR, this increases the need for a high-performance PC and the potential for performance issues on older or underperforming systems. These issues can lead to more crashes, loss of work, and inflated time-requirements. Another key issue to note is the heavy reliance on the datasets available on the *OpenTopography* website, which can be inconsistent. This method also requires the most supplemental software of any of the methods explored in this study and larger datasets can take much longer to process. With the pros and cons considered, the steps for generating a topographic surface using the LiDAR method are as follows:

- *Step #1:* Locate/process the desired dataset on *OpenTopography* based on the site location and the available information. This process will generate a "LAZ" file containing a point cloud of the desired area that can be downloaded. Once the file is generated, *OpenTopography*'s web-based LiDAR view can be used to verify the quality of the dataset. For the sake of this study, the *2003 NCFMP LiDAR: NC Statewide Phase 2* (Concord Hillgrove WTP) and the *USGS LPC FL PalmBeachCo 2016 LAS 2019* (PBC WTP 2) datasets were used.

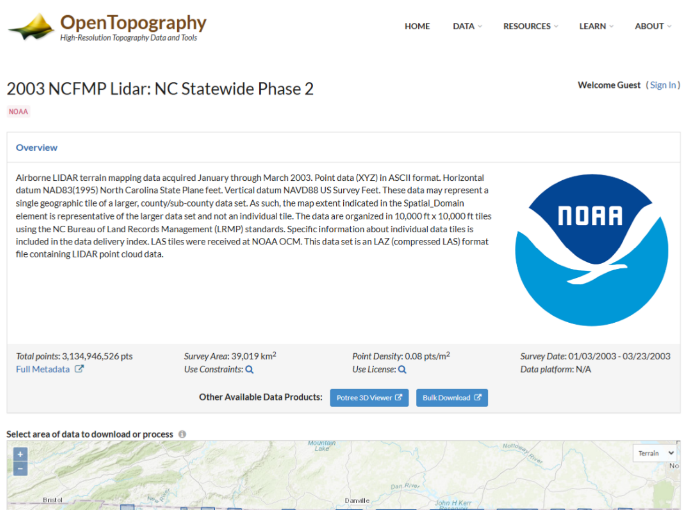

Figure 3.2.1.8: OpenTopography Dataset Download Page

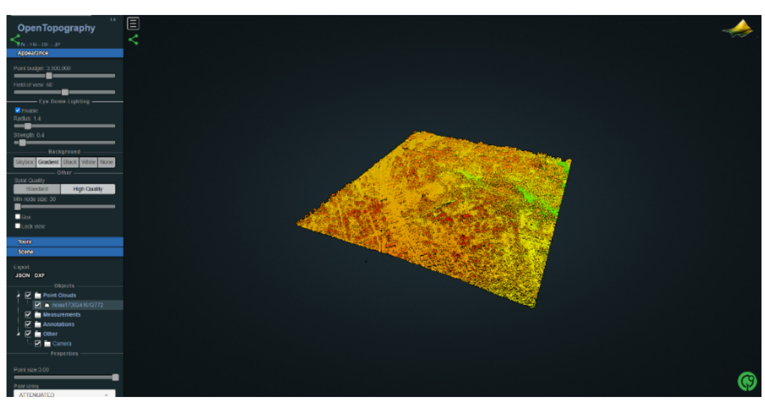

Figure 3.2.1.9: OpenTopography's Web Based LiDAR Viewer

- *Step #2:* Import the downloaded "LAZ" file into Autodesk ReCAP and export the project as a "RCS" file. This process is time consuming for larger datasets, but it allows the point cloud to be inserted directly into a Revit model.
- *Step #3:* As mentioned above, insert the "RCS" file directly into a Revit 2023 model using the import point cloud feature.

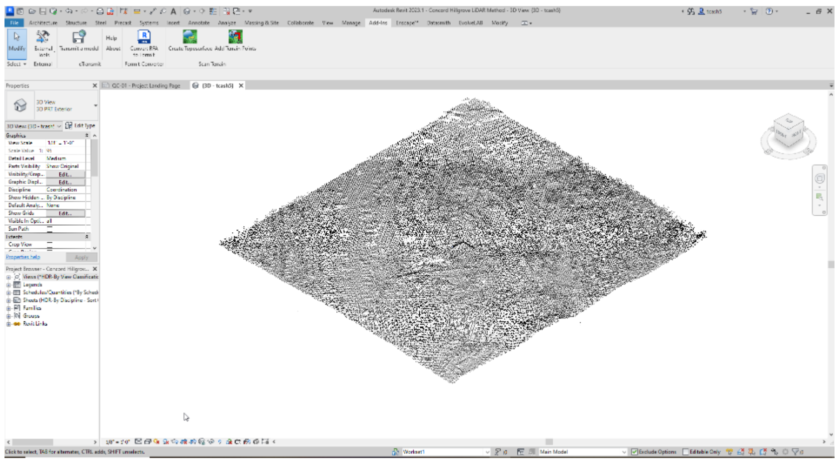

Figure 3.2.1.10: Point Cloud Imported into the Revit Model Space

- *Step #4:* Utilize the *Scan Terrain* Plug-in for Revit 2023 to generate a "Topo Surface" in Revit. The plug-in will ask for key information regarding the site with an onscreen UI. Unfortunately, this plug-in is not available for Revit 2024 due to the recent addition of "Topo Solids" and the need to re-work the generation algorithm to work with the new feature.

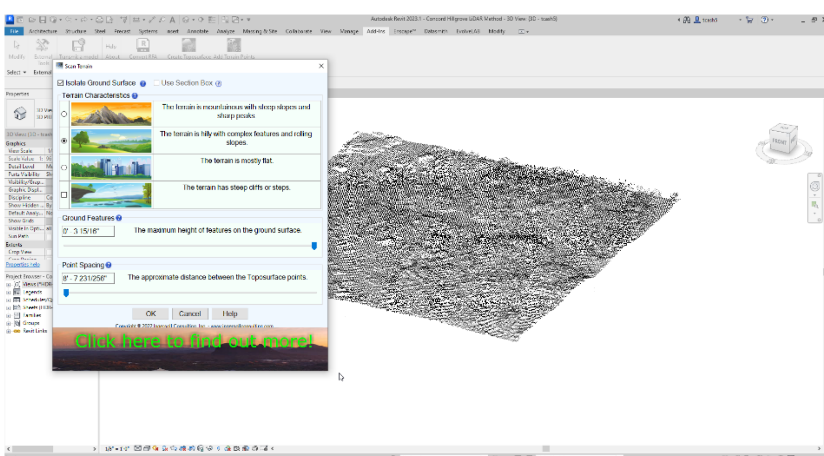

Figure 3.2.1.11: Scan Terrain Plug-in UI Within Revit

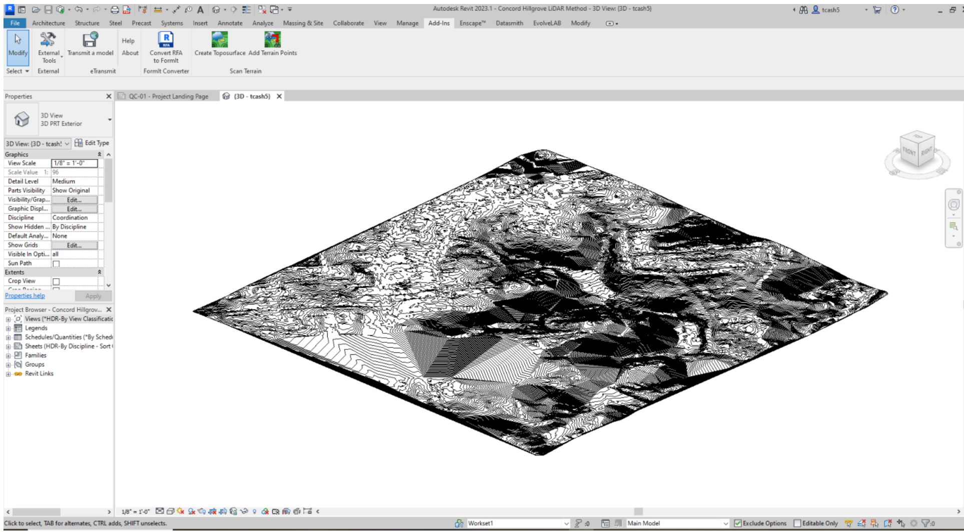

Figure 3.2.1.12: Topo Surface Generated Using Scan Terrain

- *Step #5:* Save the project in Revit 2023 and open it back up in Revit 2024. Upon selecting the created "Topo Surface", The user will be prompted to generate a "Toposolid." After generating the "Toposolid", the process of generating a topographic surface is complete and the surface is ready for the creation of features such as roads, waterways, building pads, sidewalks, etc. using traditional methods. This process may require some cleaning of the surface, as the LiDAR data produces a very complex topographic surface, which may create some minor errors within Revit.

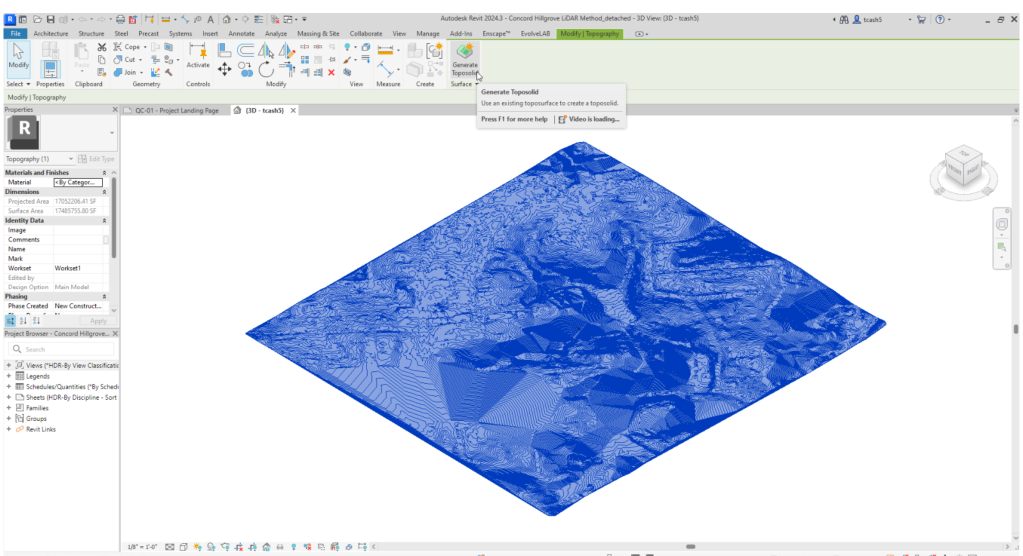

Figure 3.2.1.13: Generate Toposolid Prompt Within Revit 2024

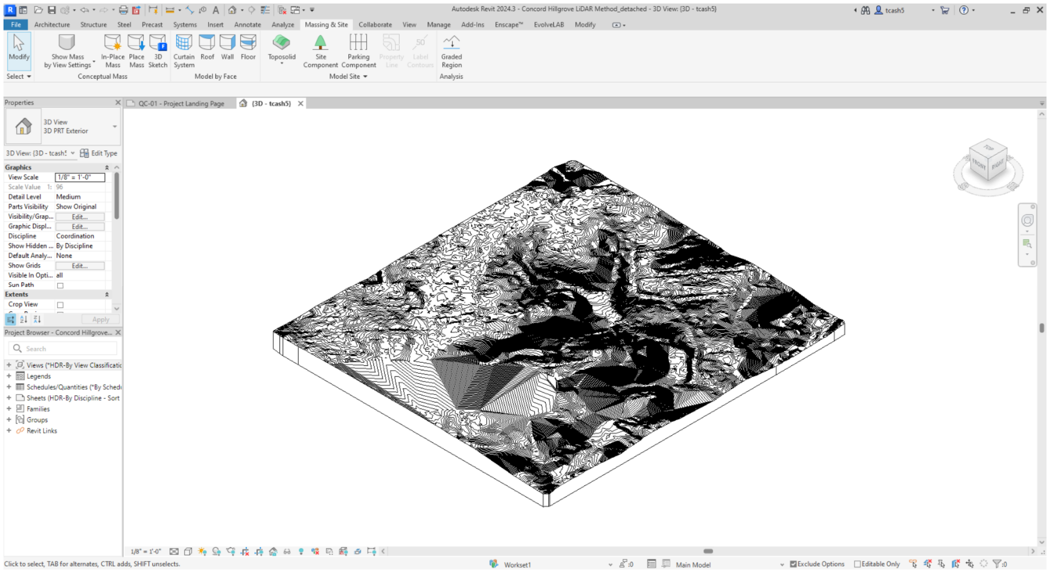

Figure 3.2.1.14: Final Topographic Surface Generated Using the LiDAR Method

Proposed Workflow #2: The CAD Mapper Method

The second workflow being considered by this study as a potential replacement for the existing workflow for topographic surface creation is the CAD Mapper Method. This method utilizes an online tool called CAD Mapper that generates a downloadable “DXF” file with 3D contour lines that can be imported into Revit and used to generate a topographic surface. CAD Mapper allows users to define an area on the map and the tool quickly generates contours based on publicly available datasets. The tool will allow users to generate up to 1 km² of contours for free, although larger areas can typically be purchased for under $10. In the case of this study, the site for PBC WTP 2 was 10.34 km² and the file cost approximately $7.60. There are many positive results associated with this method including the ability to rapidly produce accurate topographic surfaces directly in Revit, the small number of steps required, the simple process, and the consistent time requirements. This method also generates basic geometry for all existing buildings, roadways, and sidewalks which aids in the modeling of existing elements. While the experience is overwhelmingly positive, there are a few key issues with this method. The first of these issues is the aforementioned requirement of purchase for files over 1 km². While the cost is relatively low for the product that is being received, this is still something that needs to be considered when selecting the method to adapt into the proposed "best practice" workflow. Another issue with this process is the tendency for this method to produce simplified topographic surfaces. Although accuracy is not imperative for a visualization model, especially one produced in the early-pursuit stage, it is important to consider if this simplification produces a sub-par final product. With the pros and cons considered, the steps for generating a topographic surface using the CAD Mapper method are as follows:

- *Step #1:* Utilize the map on the CAD Mapper website to find the site and specify an area which requires contours to be generated. For the purposes of this study, contours will be generated every 4 meters, and the road geometry will be generated as mesh surfaces. This represents the highest form of accuracy that the CAD Mapper tool can provide.

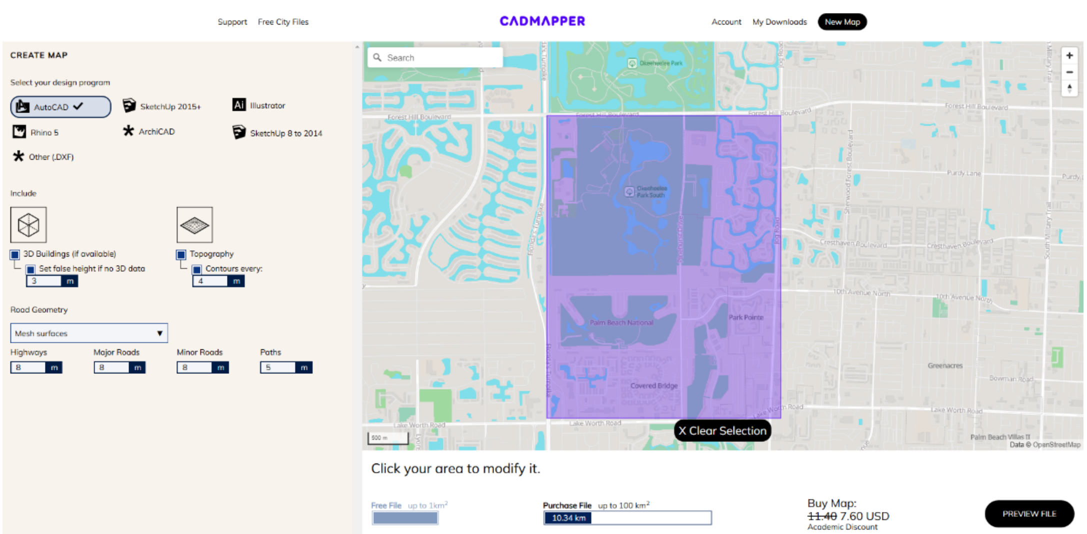

Figure 3.2.1.15: CAD Mapper UI with PBC WTP 2 Site Selected

- *Step #2:* Generate and download the "DXF" file. If the site is larger than 1 km², the user will be prompted to purchase the file before the generation process begins. The quality of the file can also be verified through the 3D Axonometric view provided by CAD Mapper's in-browser viewer.

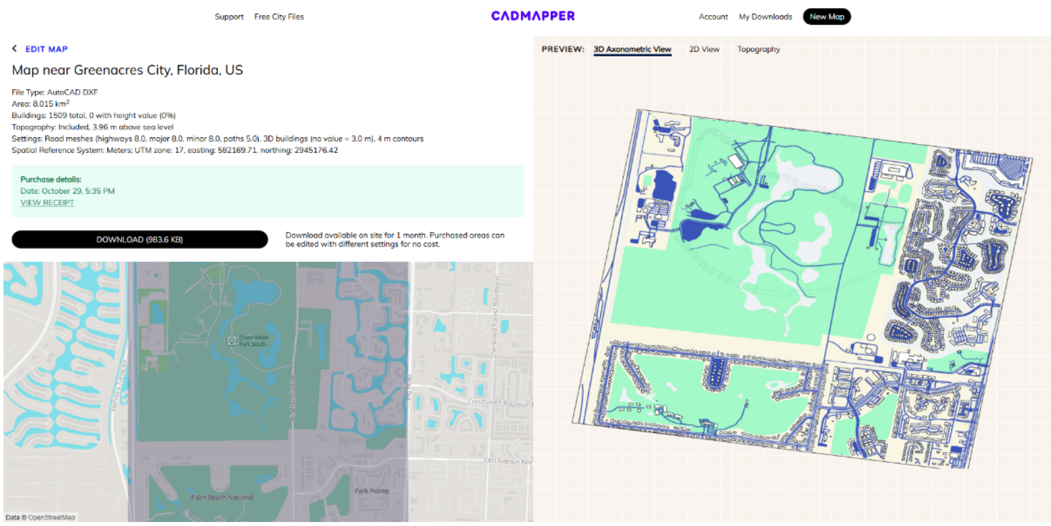

Figure 3.2.1.16: CAD Mapper's Download Webpage with In-Browser Viewer

- *Step #3:* Import the downloaded "DXF" file into Revit 2024 by utilizing the "Import CAD" feature.

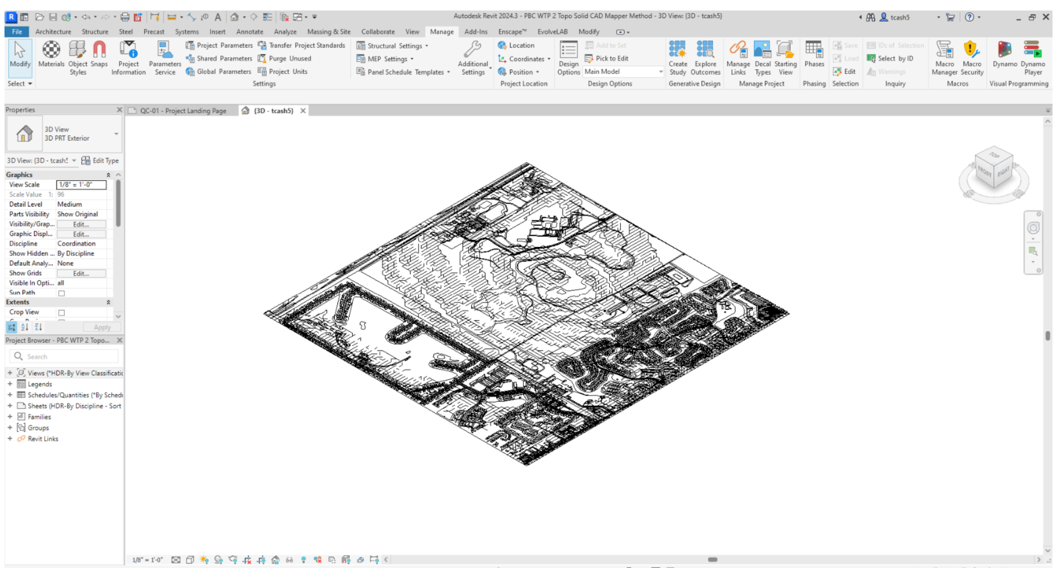

Figure 3.2.1.17: "DXF" File Imported into Revit Model Space

- *Step #4:* Generate a "Toposolid" using the "Create Toposolid from Import" feature in Revit 2024. This feature will allow users to select the CAD layers that will be utilized for the process of generating the surface. Typically, it is best practice to generate surfaces from the "contours" and "topography" layers in order to avoid imperfections in the generated surface, although different sites require experimentation to ensure the best outcome. After generating the 'Toposolid", the process of generating a topographic surface is complete and the surface is ready for the creation of features such as roads, waterways, building pads, sidewalks, etc. using traditional methods. This method may require some slight cleaning of the surface, as with any other rapid generation method.

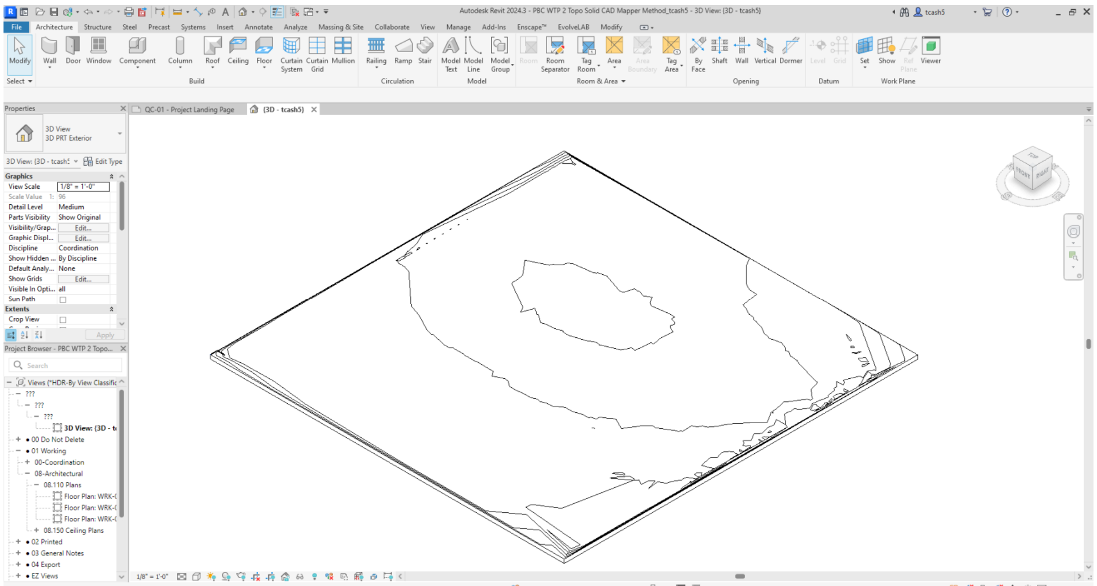

Figure 3.2.1.18: Final Topographic Surface Created Using CAD Mapper Method

Adding Features to a Topographic Surface

Although this research does not explore new methods for adding features (roads, waterways, building pads, sidewalks, etc.), outlining the existing workflow is important to adding context and allowing the reader to understand the time required to create the site for a visualization model. Through the many modeling tools offered in Revit, BIM designers must carefully create site features that reflect the "real world" around the project site. One common process, regardless of the feature being created, is to insert a scaled screenshot directly into a floor plan within Revit and to set the transparency of the topographic surface to approximately 80% (See Step #3 from the Google Earth Method). This allows designers to trace the desired feature in plan view and quickly develop the desired 3D element. As mentioned above, for the sake of brevity, it would be unnecessary and outside the scope of this research to provide step-by-step instructions for each modeling process. Therefore, to provide a brief overview of the key features that must be added, and the "best practice" modeling techniques please see the table below:

Table 3.2.1.1: Features for Topographic Surfaces and "Best Practice" Modeling Techniques

Feature	"Best Practice" Modeling Technique
Roads, Sidewalks, and Curbs	Using the Sub-Divide feature in Revit, create a sub region in the "Toposurface." Draw in the desired element and finalize the sub-division. After creating the sub-division, set the sub-divide height in the properties menu (4" for roads/sidewalks and 6" for curbs).
Building Pads	Using the floor feature in Revit, create a floor that represents the building pad. Typically, a building pad is modeled as a 12" thick concrete floor and set at the appropriate finish floor elevation. In order to remove the "Toposolid" in the area of the building pad, use the Cut tool and set the building pad to cut the "Toposolid."
Waterways and Water Features	Using the Model in Place feature in Revit, create both an extrusion and a void extrusion to represent the waterway. Set the void extrusion to cut the "Toposolid" and ensure that it extends to the bottom of the extrusion that represents the water. For the extrusion that represents the water, set the material to a water type that reflects the true color of the waterway or water feature.
Berms and Miscellaneous Graded Regions	Using the Modify Sub Elements feature in Revit, modify the points on the "Toposolid" to either raise or lower the grade, as needed.

Comparing Topographic Surface Generation Methods and Selecting a Preferred Method

When attempting to select the preferred method for topographic surface generation to apply to the proposed "best practice" workflow, it is important to consider multiple KPIs (Key performance indicators) to ensure that the best workflow is selected. The first and most important of the KPIs is the time that it takes to generate a complete topographic surface with each methodology. For the convenience of the reader, the time requirements of creating the topographic surfaces for each case study utilizing each workflow have been provided in the tables below:

Table 3.2.1.2: Google Earth Method Time Requirements

Google Earth Method	PBC Completion Time (Hrs.)	Concord Hillgrove Completion Time (Hrs.)
Screenshot Google Earth Image	0.05	0.05
Insert Image into Revit and Scale	0.017	0.02
Create Topo Solid from Sketch	0.05	0.05
Use elevations from Google Earth to Build out Topo Solid	10	15.00
Total	10.12	15.12

Table 3.2.1.3: LiDAR Method Time Requirements

LiDAR Method	PBC Completion Time (Hrs.)	Concord Hillgrove Completion Time (Hrs.)
Source Data	1.50	0.17
Export LAZ To ReCAP	0.33	0.08
Export to RCS in ReCAP	4.75	0.08
Import Point Cloud to Revit 2023	0.08	0.08
Use Scan Terrain Plug-in to Convert LiDAR to Topo Surface	0.75	0.25
Import Topo Surface to Revit 2024	0.08	0.08
Convert Topo Surface to Topo Solid	0.08	0.08
Clean	0.50	0.17
Total	8.08	1

Table 3.2.1.4: CAD Mapper Method Time Requirements

CAD Mapper Method	PBC Completion Time (Hrs.)	Concord Hillgrove Completion Time (Hrs.)
Source DXF from CAD Mapper	0.08	0.08
Import DXF to Revit	0.02	0.02
Convert DXF File to Topo Solid	0.03	0.03
Clean	0.25	0.50
Total	0.38	0.63

Based on the tables above, it can be determined that the time requirements for the CAD Mapper Method are much more desirable than other methods and its results are more easily replicated across projects of varying scope, regardless of the size of the dataset utilized. In regard to visualization for pursuit, the most important KPI of a workflow is speed due to the minimal time requirements associated with pursuit projects. Therefore, in the realm of visualization projects, based on time alone the CAD Mapper Method is the most promising of the three methods being explored.

While time requirements are extremely important, it is also imperative to consider another KPI for these workflows: Quality. In visualization, quality is particularly important to producing an effective end product that will convey the goals of the design team. The three methods examined produce end products of varying quality, which sets them apart from one another. The Google Earth Method's quality is determined by the skill of the designer and the commitment made to creating the surface. Therefore, this method produces final results that are extremely inconsistent and typically are not fully representative of the "real world" site context. These factors alone are disqualifying for this method due to the unpredictable quality of the final product. As for the LiDAR method, when used effectively, this method produces a near-replica of the existing topography of the area. While this method can have similar time requirements to the Google Earth Method (depending on size of dataset), it produces consistent quality in each topographic surface created. The CAD Mapper Method works extremely well with Revit's core functions in order to create topographic surfaces with an average quality. While the quality of CAD Mapper's surfaces are not 100% accurate, typically the quality of surface that is produced is passable for the purposes of model visualization.

Another KPI that is important to consider is the cost of utilizing each method examined above. While some tools may be free to use, the hourly labor burden rate of the BIM Designer must be considered as well. In the case of this study, a labor burden rate of $42.48 will be utilized. Based on this information, the cost of creating topographic surfaces with each method is as follows:

Table 3.2.1.5: Google Earth Method Cost

Google Earth Method		
	PBC WTP 2	Concord Hillgrove
Total Hours	10.12	15.12
Direct Hours (Charged Hours)	10.12	15.12
Idle Hours (Uncharged Hours)	0	0
Labor Burden Rate ($/Hr.)	42.48	42.48
Cost of Labor ($)	429.90	642.30
Cost of Tools ($)	0	0
Total Cost ($)	429.90	642.30

Table 3.2.1.6: LiDAR Method Cost

LiDAR Method		
	PBC WTP 2	Concord Hillgrove
Total Hours	8.08	1
Direct Hours (Charged Hours)	6.58	0.83
Idle Hours (Uncharged Hours)	1.50	0.17
Labor Burden Rate ($/Hr.)	42.48	42.48
Cost of Labor ($)	279.52	35.25
Cost of Tools ($)	0	0
Total Cost ($)	279.52	35.25

Table 3.2.1.7: CAD Mapper Method Cost

CAD Mapper Method		
	PBC WTP 2	Concord Hillgrove
Total Hours	0.38	0.63
Direct Hours (Charged Hours)	0.38	0.63
Idle Hours (Uncharged Hours)	0	0
Labor Burden Rate ($/Hr.)	42.48	42.48
Cost of Labor ($)	16.14	26.76
Cost of Tools ($)	7.60	0
Total Cost ($)	23.74	26.76

According to the information synthesized in this section, the method that will be applied for the “best practice” workflow will be the CAD Mapper Method. Based on all KPIs, this method seems to be the most promising for not only reducing the time requirements of visualization project, but also increasing the quality of these visualizations. While the LiDAR Method produces a topographic surface of a higher quality, that level of quality is unnecessary for a project that is in the pursuit phase. The complex geometry produced using the LiDAR method also creates more areas that must be manually graded by the BIM designer, which can rapidly inflate the time required to complete a topographic surface. With the CAD Mapper Method, on the other hand, the simplified surface lends itself to rapid updates to the generated topographic surface which can be useful when adding proposed graded regions. This method also requires less cleaning of the topographic surface and a lower skill requirement for designers. These facts, coupled with the low cost, are why that the CAD Mapper Method has been chosen for the “best practice” workflow.

3.2.2 EXISTING & PROPOSED EQUIPMENT MODELING

When creating visualization models for water and wastewater treatment projects, a key aspect involves the creation of various equipment families that can be inserted into the model to represent both the existing and proposed equipment. Typically, these models are created using generic geometry and are only representative of a single equipment type. Unfortunately, this often requires BIM designers to create families of assorted sizes for the same type of equipment, which can be time-consuming. A solution to this problem can be found through the creation of a library of parametric families. As opposed to generic families, parametric families allow the BIM designer to rapidly adjust the size and shape of a given family. Therefore, only a single family is needed to create several types of the same kind of equipment. The downside of parametric families is the time and skill required to effectively create working families. For the purpose of this study, while it will be provided in the proceeding pages, the time required for the creation of these families will not be considered in determining if this process is applicable to the proposed workflow. It will be assumed that, since it is not billable to a client, the time required to develop the library of common families is not associated with the creation of visualization projects, therefore it will not be considered in this research. The goal of this section is to determine if the development of this library of common equipment will provide the necessary time savings during the modeling stages to justify the time required to create it. For the scope of this project, the library will only contain the families required to complete the case studies of PBC WTP 2 and Concord Hillgrove WTP. These families include: a degassifier, an odor control scrubber, a polymer storage tank, a chemical storage tank, a ground storage tank, a fuel storage tank, a flat top storage tank with/without manway, a chemical containment tank, a cartridge filter, a vertical turbine pump, a generator, an electrical control panel, a GAC contactor tank, and a water tower.

This section will also explore utilizing Dynamo, a visual programing software for Revit, to rapidly reshape and resize the families. Through the process of developing a script that can quickly assign parameters to a family through Dynamo Player, a UI for running dynamo scripts, there is potential to both reduce the time required to resize these families and will simplify the process for less experienced designers. It was assumed that every parametric family in the aforementioned library would have a Dynamo script associated with rapidly resizing the family.

Generic Families Vs. Parametric Families

Generic Families, more commonly referred to in jest as “dummy” families, are families developed using only basic modeling tools. These are tools within Revit such as extrusions, cuts, voids, revolves, and sweeps. Through utilization of these tools, BIM designers carefully shape the equipment and attempt to make it look as similar as possible to its "real world" counterpart. Typically, these models are created when there are no existing models available in a company library or another available resource. While these families can be developed rapidly and have a lower skill requirement, in visualization models, there are typically many varied sizes of the same equipment which requires multiple families to be created. This can lead to increased time requirements associated with developing families of varied sizes for different sizes of the same equipment. For visualization projects, this increase in time required can lead to severe impacts to both the cost and quality of the model.

Parametric families offer a perfect solution for reducing the time required to model assorted sizes of similar pieces of equipment. The process of creating parametric families begins with the creation of a generic family, which is then constrained through assigned parameters. These parameters dictate the size and shape of the family, which allows for a single family to be utilized for multiple pieces of the same equipment. There are two main parameter types that should be noted: independent and dependent. Independent parameters are the driving parameters of the model and will have the most impact on the shape of the model, while dependent parameters are calculated based on the values assigned for each independent parameter. These parameters are assigned by the BIM designer through the "family type" menu, therefore it is important when to determine the independent parameters whilst developing the model. In the case of this study, the independent parameters will be used to modify the desired family through user input by utilizing the developed dynamos scripts. By utilizing parametric families, as opposed to generic families, this study aims to drastically reduce the time required to model both existing and proposed equipment for visualization models. While parametric families show potential for time reduction, it is important to note that, in order to make this study feasible, the parametric families often represent simplified versions of the desired equipment, which could have a slight impact on quality. It is important to determine if the time savings produced from utilizing parametric families negates any impact on the quality of the final product.

Process Overview of Creating Parametric Families

Throughout the duration of this study, fourteen parametric families were developed in order to create a sample library of common equipment. While the modeling process varied slightly between families, the same general steps applied to the creation of each. These steps are as follows:

- *Step #1:* Develop a generic family that represents the desired piece of equipment. For this step-by-step overview, the GAC contactor family will be provided as an example.

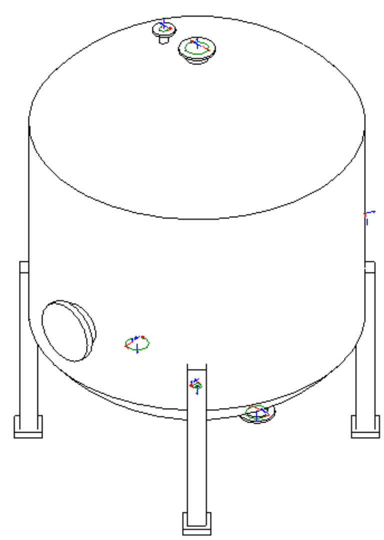

Figure 3.2.2.19: Generic Family of a GAC Contactor

- *Step #2:* Draw reference lines and reference planes over key areas of the model. After drawing these lines/planes, lock the model's geometry so that it is associated with the desired line or plane. This process can be time-consuming, as every piece of model geometry must be properly constrained in order for the family to work correctly.

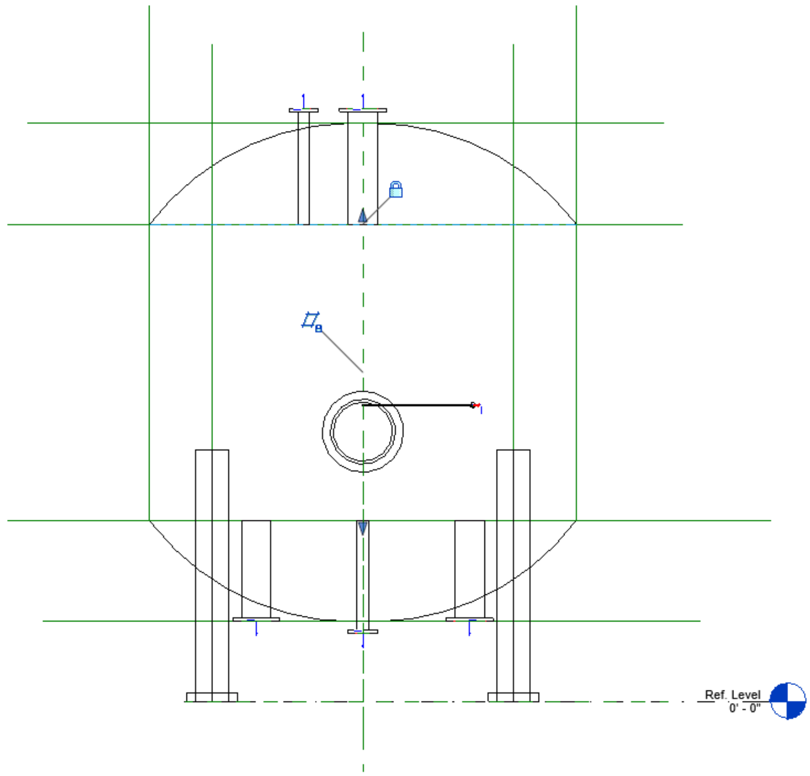

Figure 3.2.2.20: A Front View of the Family Showing Reference Lines and Locked Geometry

- *Step #3:* Create dimensions between the reference lines/planes and assign labels to each. This process will prompt the BIM designer to create type parameters from these labeled dimensions.

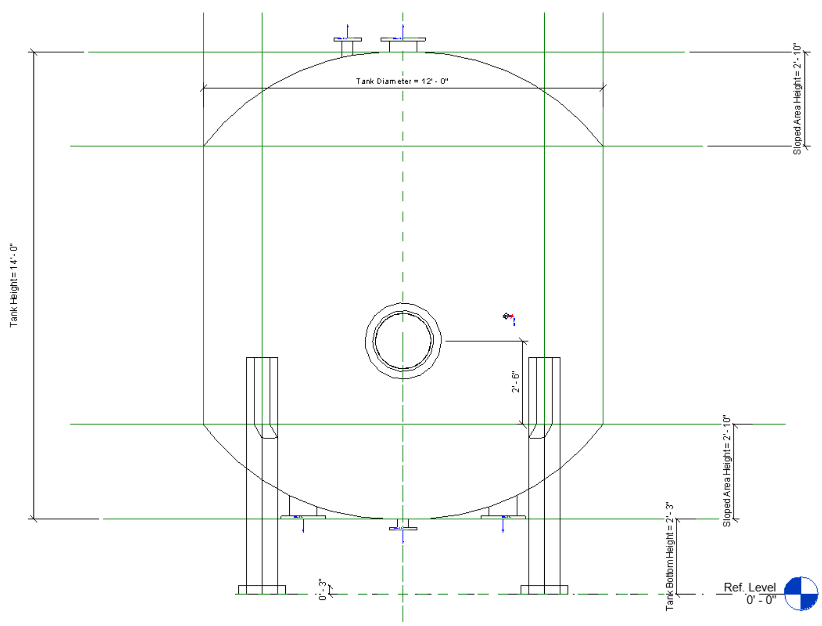

Figure 3.2.2.21: Front View of the Family Showing Labeled Dimensions

- *Step #4:* Determine the independent and dependent parameters. In the case of the GAC Contactor family, the following independent parameters were determined: Tank diameter, tank height, bottom connection 1 diameter, bottom connection 2 diameter, side connection diameter, top connection 1 diameter, top connection 2 diameter, and manway diameter. After determining the independent parameters, utilize formulas to calculate the dependent parameters based on the values assigned to each of the independent parameters. If this process is completed correctly, the family is now parametric.

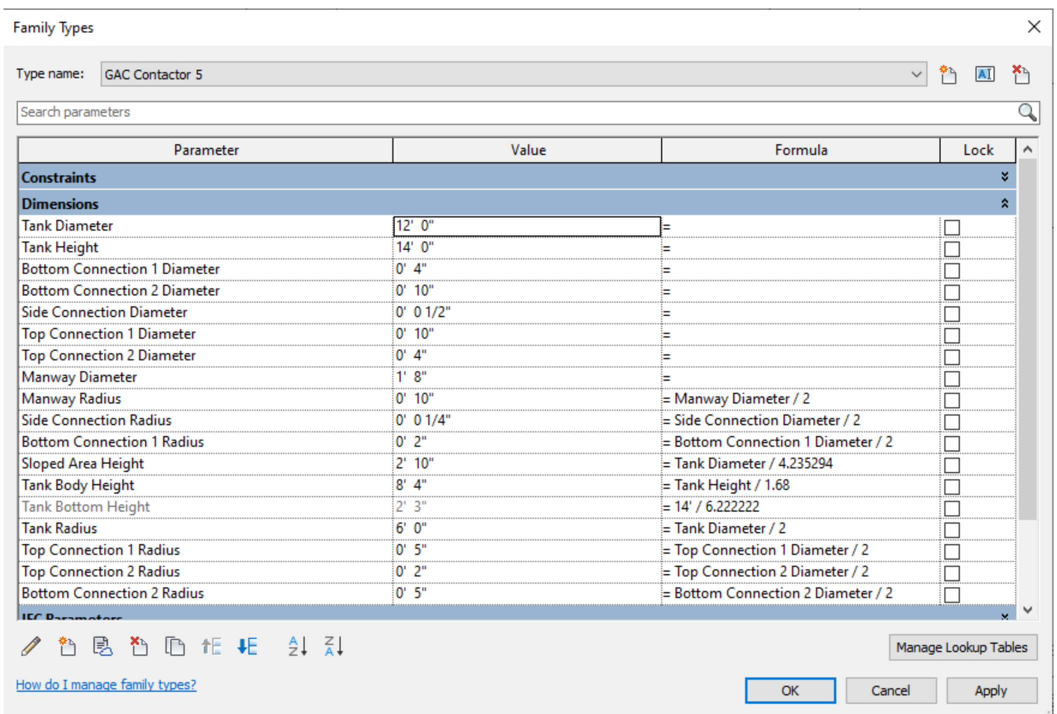

Figure 3.2.2.22: Family Type Window Showing Both Independent and Dependent Parameters

Dynamo Scripting Process Overview

In conjunction with developing each parametric family, a dynamo script was developed in order to aid in the process of manipulating this equipment within the model (see Appendix A for Dynamo scripts). While this process varied from family to family, it is relatively similar for each. In order for this scripting process to work, for each family, 5 family types were created with the following nomenclature: *Equipment Name N*. For example, using this naming convention, the first family type for the GAC Contactor would be named *GAC Contactor 1*. With this process, the script will be able to edit the parameters of 5 types of the same equipment family in order to dimension each instance within the model. These scripts utilized open-source nodes within the Dynamo packages *Rhythm* and *Beyond Dynamo*. The steps for the creation of these scripts are as follows:

- *Step #1:* Within Dynamo, develop a script group that will allow users to select all instances of a desired family through drop down menu. This process utilizes a Boolean filter in order to obtain all instances of the selected family.

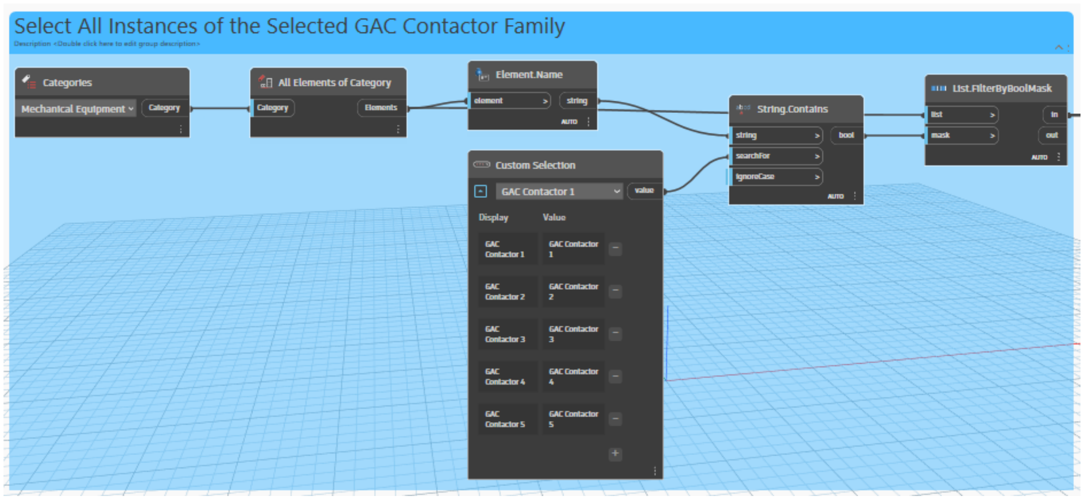

Figure 3.2.2.23: Script Group that Selects All Instances of a Desired Family

- *Step #2:* Create script groups for each of the independent parameters that will allow users to input values for each parameter. In some cases, the desired input is in the wrong units and must be converted for the script to function properly. For instance, if the desired input is in inches, the input value must be divided by twelve because Revit only accepts parameter measurement values in feet or meters depending on project units.

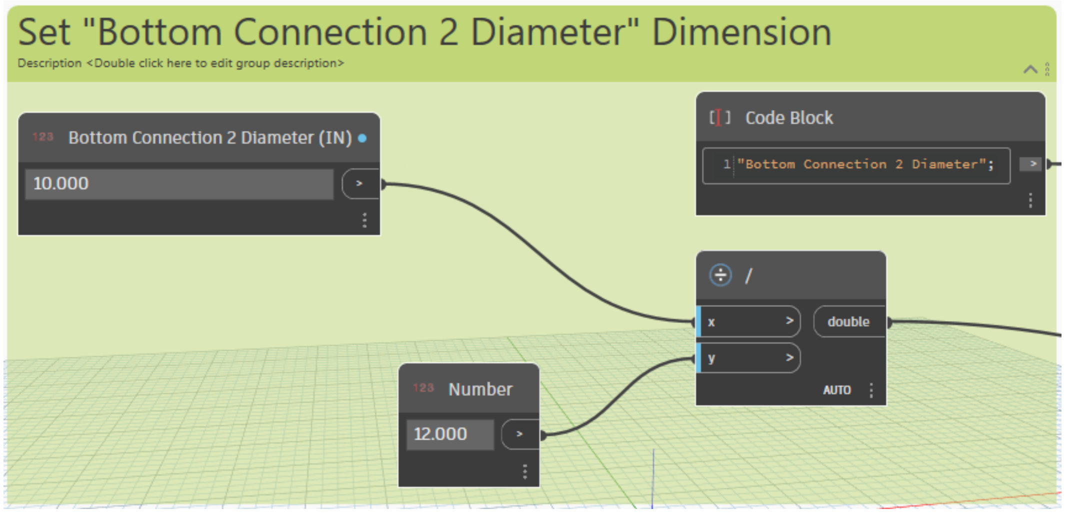

Figure 3.2.2.24: Script Group that Assigns a Parameter Value for a Given Parameter

- *Step #3:* For the script groups created above, connect the code block with the parameter name to the parameter name input of the "Elements.SetParameterByNameType" Node from the *Rhythm* Dynamo package. After connecting the parameter name to the proper input, attach the node with the desired value to the value input of the same "Elements.SetParameterByNameType" node. The result of the Boolean filter in *Step #1* is then connected to the element input. Repeat this process until all parameters have been assigned using the "Elements.SetParameterByNameType" node.

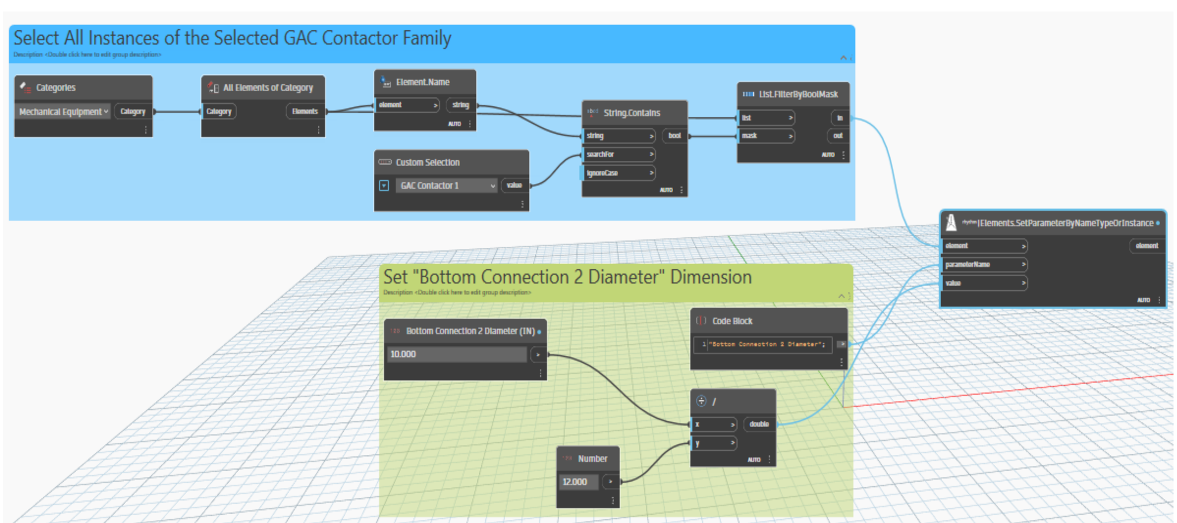

Figure 3.2.2.25: Script Groups Connected to "Elements.SetParameterByNameType" Node

- *Step #4:* Utilize the *Beyond Dynamo* package to set the order of the input nodes so that the user is prompted in the desired order within Dynamo Player. After completion of this step, the Dynamo script has been successfully created for the desired family.

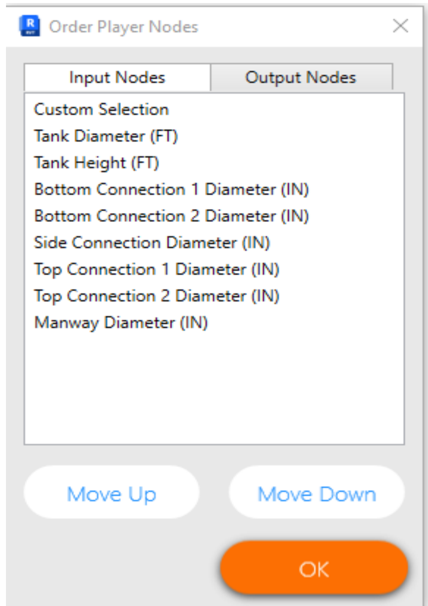

Figure 3.2.2.26: Beyond Dynamo Input/Output Order Window

Using Dynamo Player for Family Manipulation

After creating both the parametric families and their associated Dynamo scripts, the user is able to quickly insert and manipulate families within the Revit modeling space. The steps for inserting and modifying the families are as follows:

- *Step #1:* Insert the desired family into the Revit model space by using the standard workflow. After the family is in the model space, assign the correct family type. For example, if it is the first instance of a GAC Contactor, assign the *GAC Contactor 1* Type from the family selection menu.

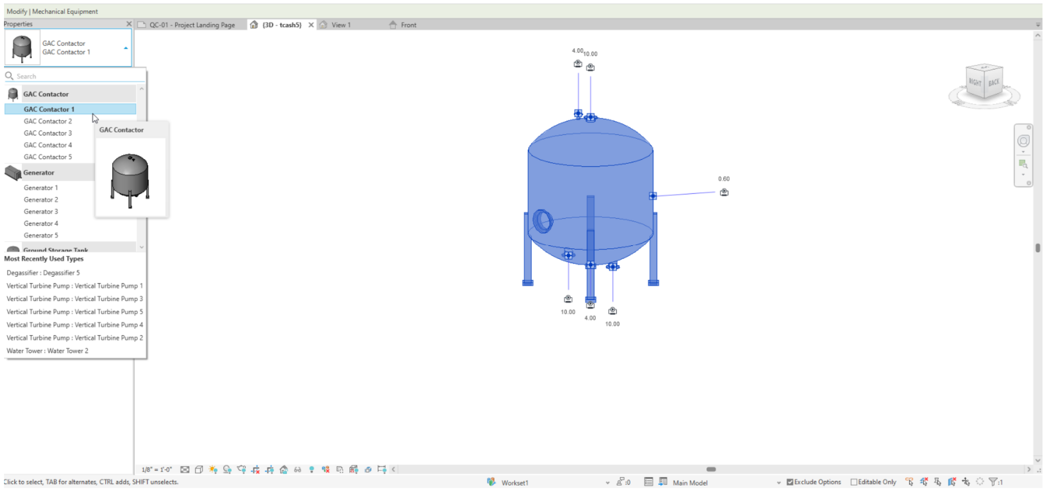

Figure 3.2.2.27: Selection of GAC Contactor 1 Family Type

- *Step #2:* Open Dynamo Player through the "Manage" tab and select the script for dimensioning the inserted family.

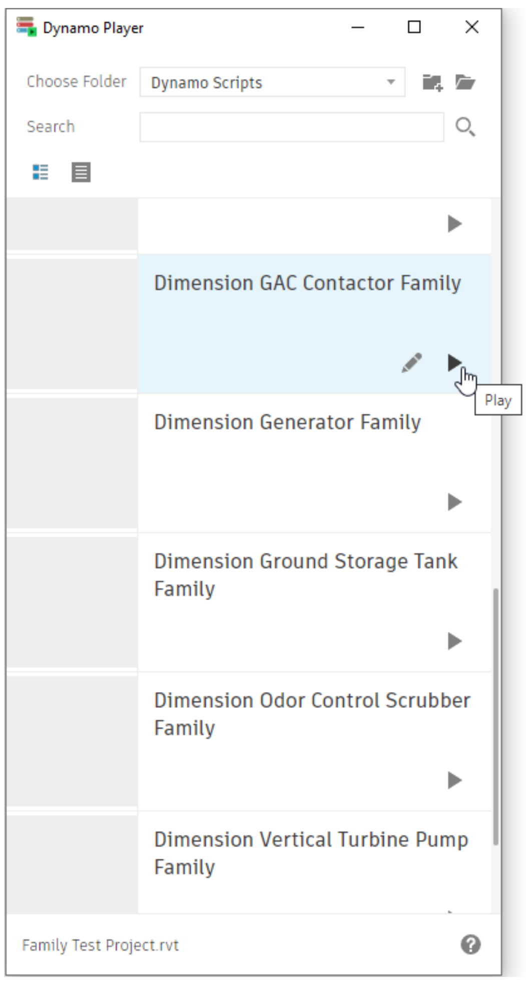

Figure 3.2.2.28: Selection of Desired Script in Dynamo Player

- *Step #3:* Open Dynamo Player through the "Manage" tab and select the script for dimensioning the inserted family. Using the UI, Select the desired family type and input the desired values for each independent parameter as prompted. After clicking Run, the family will automatically update to reflect the input values. Odd shapes will prompt errors, but these can usually be ignored if the family is successfully modified. If there are errors that affect the modification of the family, this is because the user input is trying to create a shape outside of the constraints of the parametric family.

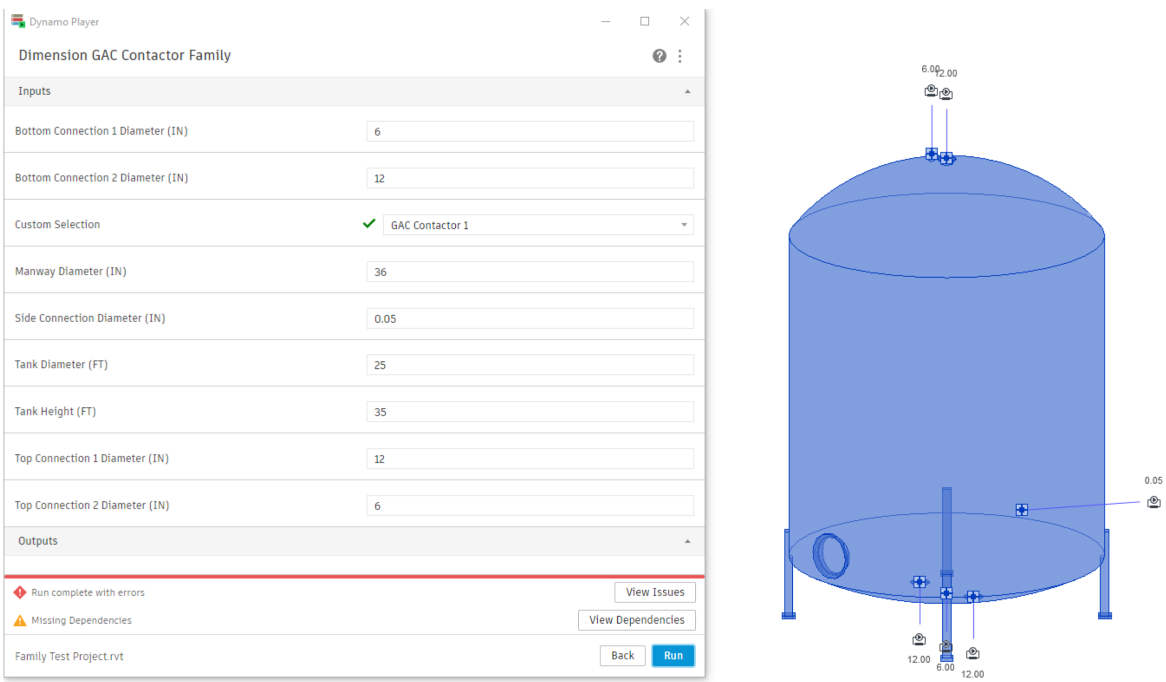

Figure 3.2.2.29: Dynamo Player with User Input and Modified Family

Comparison of Existing and Proposed Workflows

As mentioned at the onset of this section, a library of fourteen parametric families and Dynamo scripts was developed to aid the two case studies being developed in this study. Since creating a parametric family first requires the creation of a generic family, this process has provided the average time requirements of each modeling method for existing and proposed equipment. By examining this data, the effectiveness of the proposed workflow at reducing the time required to model equipment can be determined. For a breakdown of the average and total time requirements for each workflow, see the tables below:

Table 3.2.2.1: Avg. Time Requirements for Family Development (By Method)

Avg. Time Requirements for Family Development (By Method)	
Traditional Modeling Method (Mins)	41.00
Parametric Modeling Method (Mins)	72.92

Table 3.2.2.2: Avg. Time Requirements for Modeling/Placement of a Single Element

Avg. Time Requirement for Modeling/Placement of a Single Element	
Traditional Modeling Method (Mins) *(Generic Modeling & Placement)*	42.00
Parametric Modeling Method (Mins) *(Placement Only)*	1.00

Table 3.2.2.3: Total Time Requirements for Family Development (By Method)

Total Time Requirements for Family Development (By Method)	
Traditional Modeling Method (Hours)	6.40
Parametric Modeling Method (Hours)	20.08

As mentioned earlier in this chapter, the time requirement for developing the parametric library and the associated Dynamo scripts will not be considered in determining the effectiveness of the workflow, as it is assumed that this library is existing at the onset of any given visualization project. Although it is not considered, on average, it takes approximately 31.92 minutes to convert a generic family into a parametric family, while the creation of a generic family only takes around 41.00 minutes. For all fourteen families, it took approximately 6.40 hours total to model them generically, while it took around 20.08 hours to create both the parametric families and the associated dynamo scripts. The key factor that will be considered is the time required to place a single equipment family into the model. It will be assumed that it takes approximately 1 min/instance to place a model using both the existing and proposed workflows. For generic families, the modeling time will also be considered in the placement time since that every instance of an element placed must be modeled individually. For parametric families, only the placement time will be considered because each instance can quickly be modified using the Dynamo scripts created for this project. Therefore, according to the data collected in this section, it only takes an average of 1 minute to place and modify a parametric family, while it takes an average of 42 minutes to place and modify a generic family. This constitutes a massive reduction of the time required to model equipment families in visualization models, given there is a useful library of parametric families readily available at the onset of the pursuit project.

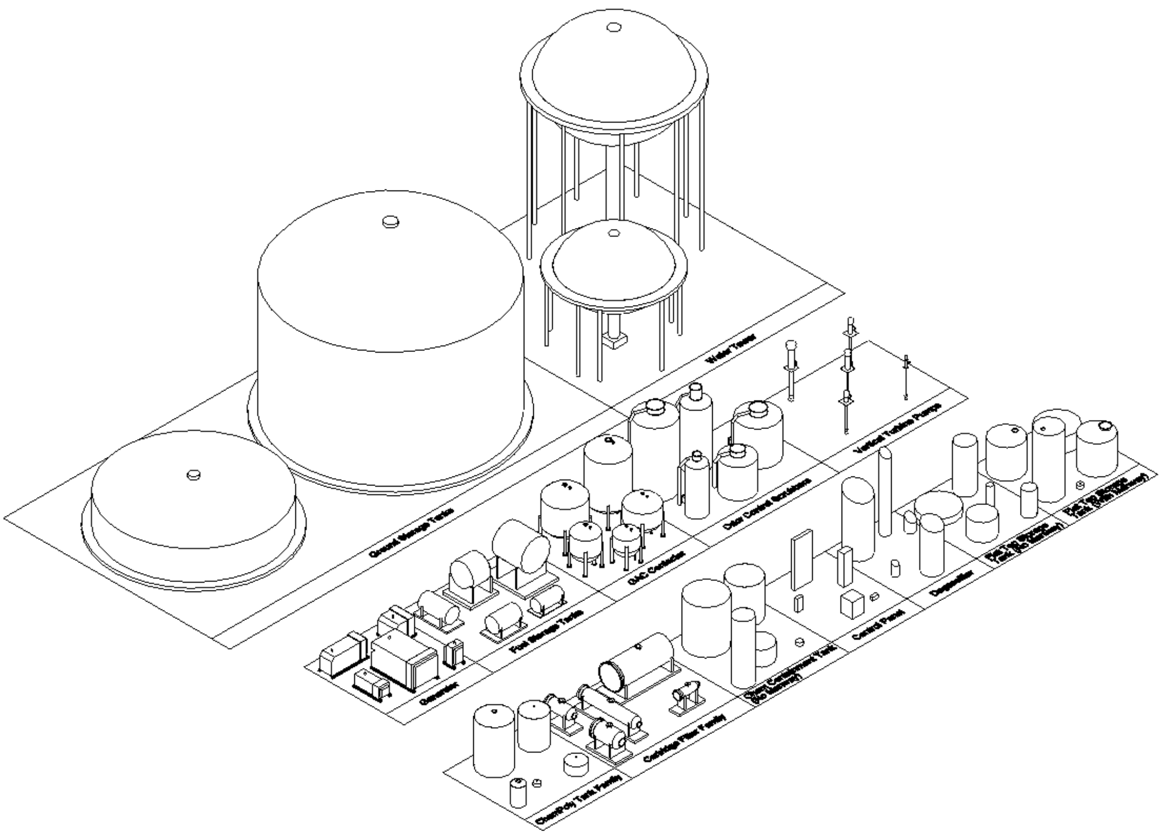

Figure 3.2.2.30: Created Library of Parametric Families

While the time reduction is extremely impressive, it is also important to consider the impact that utilizing these parametric families has on quality of the final model. In order to create effective parametric families, this process sometimes requires the simplification of the family to allow its elements to be properly constrained. While this simplification is usually acceptable in a pursuit project, it would be important to consult with the pursuit team to determine if this reduction of detail will have a negative impact on the visualizations produced from the model. To conceptualize the differences in detail that must be considered when selecting a workflow, as shown in the figure below:

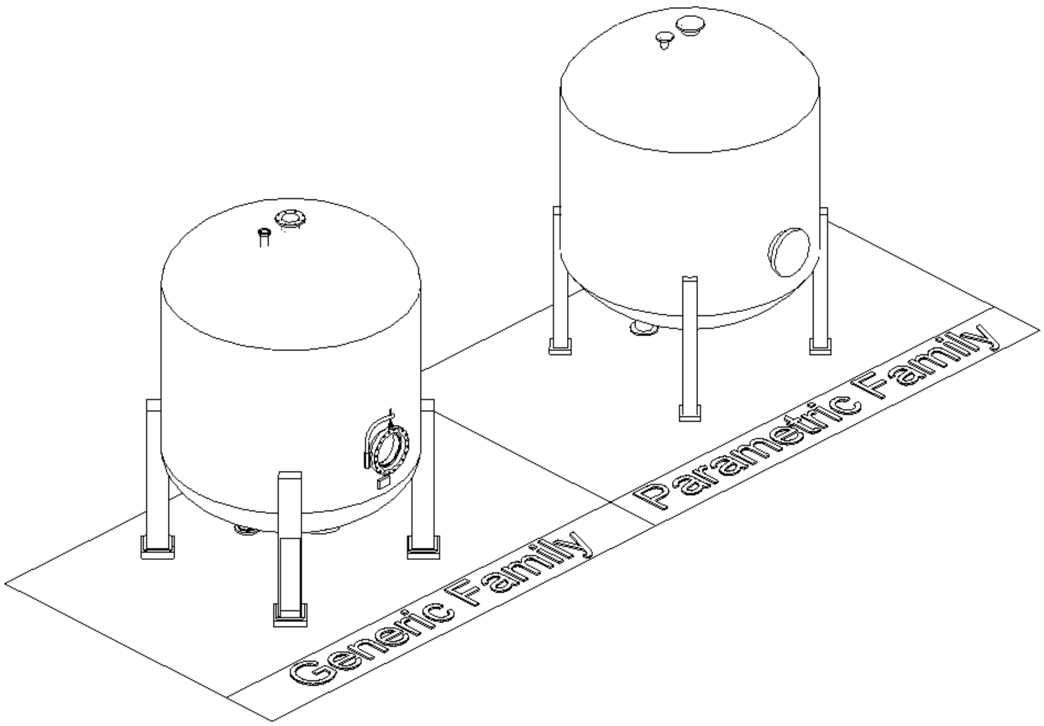

Figure 3.2.2.31: Details of Generic Families vs. Parametric Families

Though there is a slight reduction in the detail of a model when it is converted into a parametric model, the time saved by utilizing the proposed method for the modeling and placement of existing/proposed equipment families far outweighs any reduction potential of quality. In theory, this method could reduce the time required to model equipment for visualization projects by hours, thus reducing the cost associated with this task. When utilizing this workflow, the cost of inserting a parametric family into the model is approximately \$0.70/instance, which is a major improvement over the \$29.03/instance when using the generic modeling method (based on a labor burden rate of \$42.42 per hour). Therefore, based on these factors, the parametric modeling method will be adapted into the "best practice workflow" for the creation of both existing and proposed equipment families.

3.2.3 AI RENDERING OF PROPOSED STRUCTURES

In model visualization for pursuit projects, many times it is necessary to develop renderings of proposed structures in order to properly convey the pursuit team's intent. Based on these initial models, the pursuit team can also fine tune their initial concepts before presenting their ideas to the potential client. While traditional methods for developing models of proposed structures are generally effective in assisting with these processes, the potential to utilize AI to rapidly develop multiple iterations of the initial design concept and stunning renders of each iteration is intriguing. Through utilizing AI rendering models, such as EvolveLAB's Veras, there is immense potential to reduce the time required to create renderings of proposed structures and also reduce the modeling effort required to create multiple options for the pursuit team to further develop. In order to determine the effectiveness of Veras, a stable diffusion model, it was evaluated on models developed to both high levels of detail (HLOD) and low levels of detail (LLOD). The following section outlines a general workflow for creating AI renderings in Veras, a comparison of results achieved at various levels of detail, tips for effective prompt engineering, and a final analysis of the workflow.

Workflow for Creating AI Renderings Using EvolveLAB's Veras

Developing effective AI renderings through EvolveLAB's Veras, just as with any image-to-image AI model, is an iterative process and the quality of the final rendering is determined through effective prompt engineering. Even with effective prompt engineering, sometimes the model can generate undesirable results which increases the number of iterations required to produce the desired result. One of the benefits of utilizing EvolveLAB's Veras is that it is built directly into Revit as a plug-in and allows users to rapidly create multiple iterations by following a straightforward workflow. The step-by-step workflow for creating these iterations of AI renderings is as follows:

- *Step #1:* Create an initial 3D view of the desired structure within Revit by utilizing the "Camera" tool under 3D view creation. For the purpose of simplifying the model for Veras, any unnecessary structures or model elements are excluded from the view.

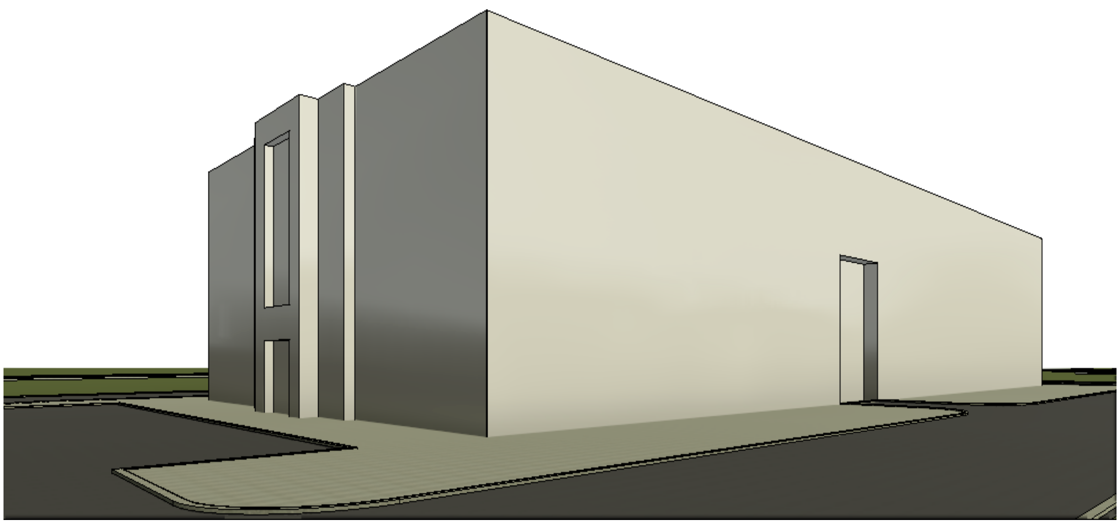

Figure 3.2.3.32: Initial 3D View of a Revit Model Prepared for Veras

- *Step #2:* Launch EvolveLAB's Veras through Revit, apply a template, and engineer an initial prompt. Veras offers many default templates that allow users to rapidly set up new prompts, although for water treatment projects these templates typically need modification. In the event that there are multiple structures that need to be rendered in a similar fashion, Veras allows the user to create custom templates that quickly applies all settings and prompts to a new image.

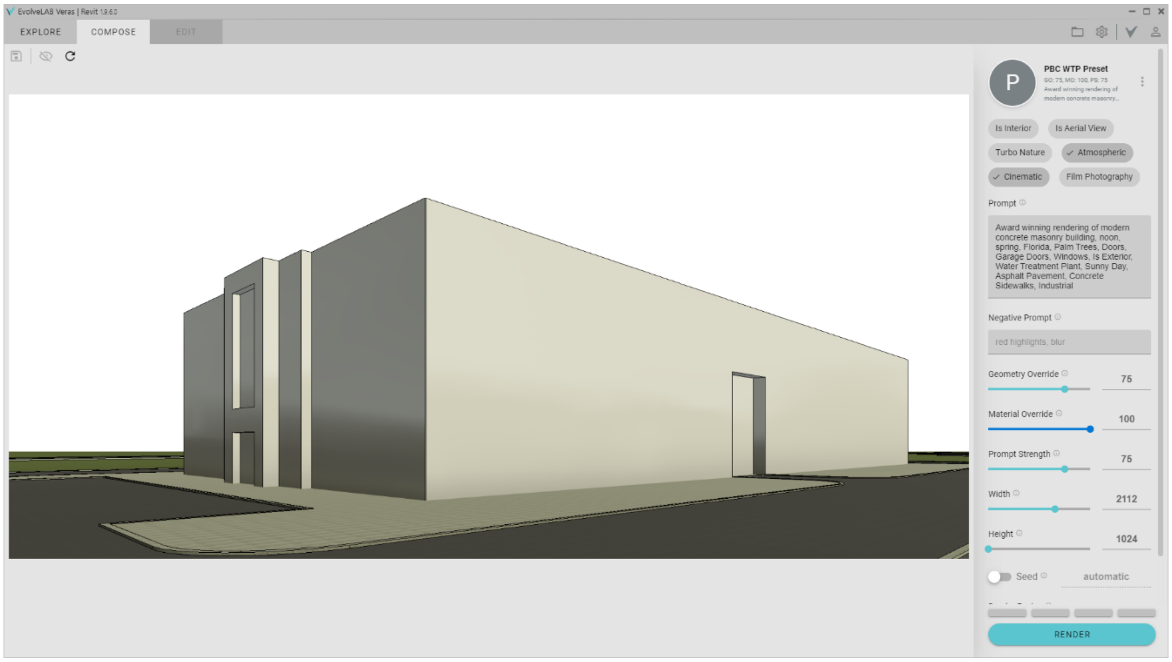

Figure 3.2.3.33: Prompting Window Within EvolveLAB's Veras

- *Step #3:* Render multiple iterations of the model image until there are a few promising candidates for the final rendering. Veras allows users to generate four iterations of AI renderings each time they run the program. If the results are undesirable, add or subtract items from the prompt and adjust the settings as needed.

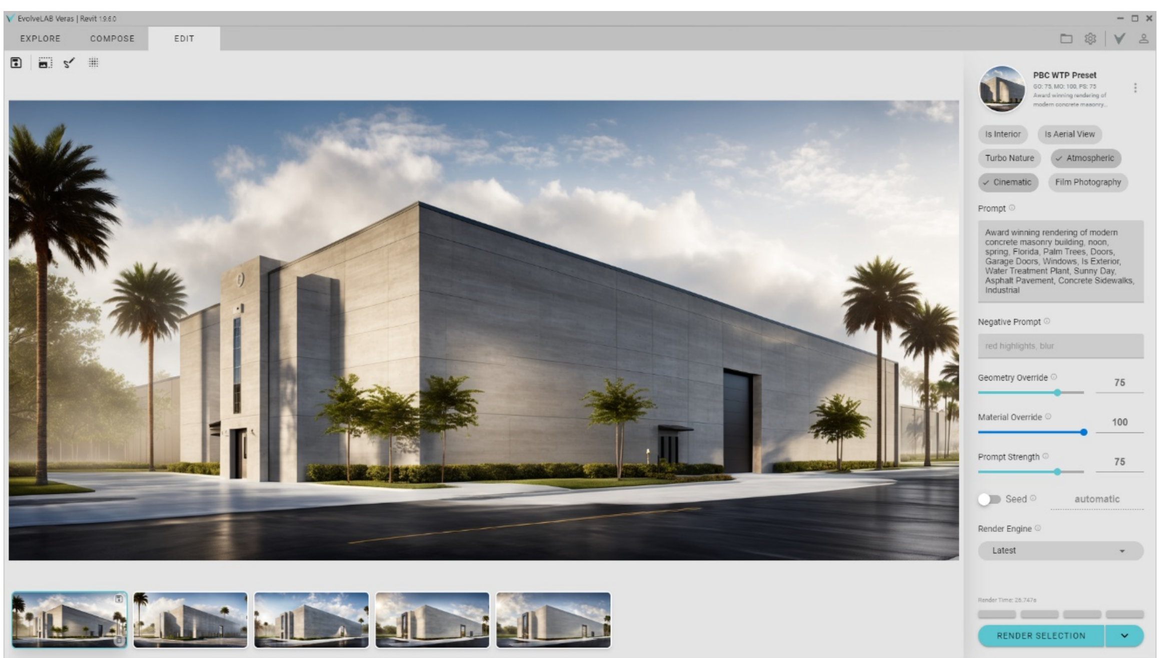

Figure 3.2.3.34: First Iteration of Model Rendering in Veras

- *Step #4:* Once the promising candidates are generated, use the edit tab to enhance each image. In the event that an image is desirable aside from a few minute details, there is also a render selection tool that allows users to define areas that they want to re-render. Through this editing process, the user can refine the promising images before selecting the image that best conveys the proposed structure.

Figure 3.2.3.35: Final Enhanced Veras Rendering of a Promising Candidate

Explanation of Veras Rendering Settings

When utilizing Veras to create renderings of Revit models, it is important to understand the key settings and their effect on the final product. The settings that have the largest effect on the generated images are geometry override, material override, and prompt strength. Through the effective manipulation of these settings, the user gains more control over the outcome of each iteration.

The first key setting, geometry override, allows users to define how much of the geometry is retained from the Revit Model. For example, iterations with a higher geometry override may produce images that are generally more random, while iterations with a lower geometry override will produce images that are closer to the Revit model's actual geometry. In situations where the model's geometry is simple and not entirely reflective of the desired end product, a higher geometry override will produce more complete results. In contrast, if a model has a higher LOD, the results of the generation are more desirable with a lower geometry override setting because the detail of the model is retained through the rendering process.

The material override setting is another key setting which allows users to determine how much of the structure's aesthetic is retained from the Revit model. This means that in the event that the overall aesthetic is well defined within the model (i.e., materials are applied and representative of the desired final look), the user should utilize a lower material override setting to retain the desired aesthetic in the rendering process. In the event that the model is developed with a lower LOD, the user should specify a higher material override in order to allow the AI model to generate new materials for the final image.

One of the most critical settings for producing stunning AI renderings is the prompt strength setting. This setting allows users to define how much the engineered prompt effects the final outcome of the rendering. When a prompt is well defined and accurately incapsulates the desired outcome, a prompt strength of 75 or higher is highly recommended. This will allow the AI model to generate more "dramatic" and interesting results that has a higher likelihood of impressing the potential client. In the event the prompt is not well defined, a lower prompt strength should be utilized to prevent unpredictable results. When using a lower prompt strength, the AI model will focus less on the prompt and more on the actual geometry of the model. In some cases where the prompt is difficult to engineer, this may produce a more desirable outcome, although it will typically be more muted and less visually interesting.

Tips for Effective Prompting

The most important key factor in producing high quality AI renderings using Veras is effective and accurate prompt engineering. Due to the fact that Veras uses a diffusion model that is prompted through structured language prompting (SLP), it can sometimes be an arduous process to train a user to effectively engineer prompts. This is because most people are comfortable with using a conversational AI, such as ChatGPT, that utilizes natural language prompting (NLP), which means that the AI model is trained to recognize natural human language when analyzing a user's prompt. Unlike NLP, structured language prompting requires users to put more thought into how they engineer their prompts. This section will focus on providing some essential ideas for developing effective prompts for EvolveLAB's Veras based on information obtained through a conference presentation given at Autodesk University 2024 (Jedrzejewski et al., 2024).

- *Prompt Contents:* When engineering effective prompts for AI renderings, it is important to consider the subject, aesthetic, style, details, art style, lighting, color palette, rendering techniques, and weather.
- *Statement Composition:* When engineering a prompt, users should focus on the overall composition to ensure desired results. It is important to separate ideas by commas and only feed the model necessary information. For example, a bad prompt that may confuse the model might say, "Give me an award-winning rendering of a concrete building in the springtime with large reflective glass windows." In order to improve upon this prompt, it should read, "Award-winning rendering of a concrete building, springtime, large reflective glass windows." This separation of ideas allows the model to search various sources and compile the necessary information to generate a more desirable image.

- *Positive vs. Negative Prompts:* An excellent feature within Veras is the ability to specify both negative and positive prompts within the UI. These features allows users to remove or add specified elements through placing them in the appropriate prompting location. In essence, positive prompts are utilized to guide the model into generating certain elements within the image and negative prompts are utilized to guide the model away from generating certain elements. For example, if a user aims to generate an image of a brick building without windows, their prompt might include a positive prompt of "brick building" and a negative prompt of "windows."
- *Clarity:* It is essential that effective prompts are clear and concise so that the AI model interprets them correctly. It is important to avoid vague or extremely general prompts, as this creates a level of unpredictability in the images that are generated.
- *Weights and Biases:* In Veras, if it is imperative that one idea has more weight than another idea, the user can place parenthesis around the key ideas to stress their importance. For example, if the user desires a rendering of a building in a heavy snowstorm, they can place prompts such as "(((blizzard)))" or "(((snowstorm)))" within their prompt to place emphasis on these ideas.
- *Prompt Order:* It is also important to consider the order in which the ideas are listed in the prompt. Based on how the AI model works, ideas placed earlier in the prompt receive more attention and are considered to be more important to producing an effective final product.
- *Ask ChatGPT:* In the event that it is difficult to craft an effective prompt, the user can utilize ChatGPT to assist in the development of an effective prompt. By utilizing ChatGPT, users can state what they desire in natural language prompt and then request a

prompt given in a structured language format. This will aid in reducing the required learning curve of using a SLP model and will help point inexperienced users in the right direction when beginning a new prompt.

Rendering Models at Various Detail Levels

In order to evaluate Veras' effectiveness in generating renderings of proposed buildings at various levels of detail, two models were developed for the proposed Granular Activated Carbon (GAC) building on the Concord Hillgrove Pursuit. One of these models was developed with traditional modeling methods and is considered to be a highly detailed model, while the other model was developed using simple extrusions and void cuts and is considered to be a low level of detail model. The goal of this section is to analyze the results produced through running each model through the iterative process of generating renderings within Veras.

As mentioned above, the highly detailed model was developed utilizing the traditional methods for modeling proposed buildings within a visualization project. This entails creating a model that consists of walls, floors, roofs, windows, doors, and any required equipment. Veras was then utilized to generate various iterations of renderings for the project and the best quality image was selected as the final result. Images of the preliminary HLOD model and the final selected AI rendering are below:

Figure 3.2.3.36: High LOD Revit model of GAC Building

Figure 3.2.3.37: Veras Rendering of the High LOD GAC Building Model

The low level of detail model was then developed using extremely generic modeling methods which consisted of creating a general shape of the desired building by utilizing both extrusions and void cuts. For this case, no materials were applied, and the generic Revit material was not modified in any way. The intent of this exercise was to determine Veras' effectiveness at inferring material and complex geometry based on the user's defined prompt. An initial image of the preliminary Low LOD model and the final selected AI rendering are provided below:

Figure 3.2.3.38: Low LOD Revit Model of GAC Building

Figure 3.2.3.39: Veras Rendering of the Low LOD GAC Building Model

While it is clear that the High LOD model produces more detailed and controllable results, the image produced from the Low LOD model represents a quality that seems acceptable for a preliminary design proposal. In the event that proposed models must be visualized quickly, Veras provides an excellent solution for expediting the creation of model visualizations through the use of simple models. There is also immense potential for utilizing Veras to develop concepts early in the proposal stage. Through developing high-level models that only represent a general shape of the final product, Veras can help produce multiple creative concepts of the same structure. This will allow the pursuit team to consider many design alternatives before further developing a proposed structure. While this low LOD result is more relevant to this study, the results Veras produced from the high LOD model are pertinent as well. Based on the HLOD example above, Veras can effectively produce photorealistic renderings of models with a higher LOD, which could provide supplemental material for pursuit teams to utilize in presentations with potential clients. This provides an alternative to the existing rapid rendering processes, although it will likely be more useful as a supplemental process in regard to highly developed visualization models.

Comparison of High LOD and Low LOD Workflows

Based on the analysis conducted in this section, it seems that EvolveLAB's Veras has great potential in assisting with the creation of high-quality visualizations of Revit models for pursuit projects. The main goal of this section was to determine if the AI rendering workflow would allow designers to reduce the level of detail in order to produce model visualizations at a higher efficiency. Two models were developed to assist in determining this, one of which was developed to the expected level of detail (high LOD), while the other was developed very rapidly with a low level of detail. The average times required to complete the models and their associated AI visualizations for each level of detail are provided in the table below:

Table 3.2.3.1: Total Time Requirements for Veras Renderings (By LOD)

EvolveLAB's Veras Average Time Requirement by LOD	
Level of Detail	**Time Requirement (Hours)**
High	3.81
Low	1.08

These average times are based on the times required to develop AI visualizations for four different proposed buildings for the two case studies that are addressed later in this work. Through this information, an average cost of $45.81/rendering can be calculated for models develop with a lower LOD, while an average cost of $161.62/rendering can be calculated for models with a higher LOD (based on a labor burden rate of $42.42 per hour). Based on this information; by developing models at a lower LOD, the company would save approximately $115.81/rendering and would reduce the average time required to complete these renderings by 71.65%.

While utilizing a low LOD model provides the aforementioned benefits, it does reduce the quality of the final AI renderings. This makes the low LOD model more desirable in situations where the time constraints or budget restrictions do not allow for the creation of a more intricate model. Therefore, the AI rendering of a low LOD model will provide a solid option in the best practice workflow for reducing the time and cost requirements for visualization projects in situations where it is deemed necessary by the project pursuit team. As mentioned throughout the section, the AI rendering of low LOD models also has immense potential in aiding in early concept development of a given design project by allowing users to produce multiple variations of the proposed building. Although this method currently will not fully replace the need for producing proposed models with a higher LOD, it is important to continue to monitor this technology as AI becomes more advanced and develops a higher level of capability.

The high LOD models provide a final rendering with quality that is constantly on par with the traditional methods for creating renderings of Revit models, although it is less predictable and controllable. Since it requires the model to be developed to a similar level of detail and has a certain level of unpredictability, this method will not fully replace the traditional workflow for creating model visualizations in the best practice workflow either. However, there is exciting potential in utilizing this method as a supplemental tool in the best practice workflow. Through effective prompting, a BIM designer will be able to produce supplemental presentation images with this method that are not limited to the visual style of the selected rendering software. Rendering software packages, such as Twinmotion or Enscape, typically have their own visual style that can easily be replicated by other firms that utilize the same software. In this instance, by utilizing Veras' AI rendering, it will allow companies to create visually stunning supplemental images in a distinct visual style that could set them apart from their competitors.

3.2.4 ENSCAPE AND TWINMOTION FOR RAPID RENDERING

When creating visualization deliverables of Revit models, it is necessary to select a rendering software package that can accommodate the needs of the project. There is a multitude of different software packages available that serve the purpose of creating visually stunning renderings of BIM models, but this study will only focus on two: Enscape and Twinmotion. Both of these programs are commonly utilized by companies to develop visualizations of BIM models and are interoperable with Revit through a plug-in. While these programs have most of the same features, some of the key functionalities are slightly different for each. For pursuit projects, it is typically up to the BIM designer to choose which software will be utilized to create the deliverables that the pursuit team is requesting for their client presentation. In some cases, due to the difference in functionality, it can be difficult to decide which of these software packages should be utilized to create the desired deliverables. This section aims to provide an overview of the functionalities of each software and provide specific use cases that can be utilized to aid in the selection of a rendering software package for a given project. The final specific use cases provided in this section will be incorporated into the proposed "best practice" workflow.

Creating Trees and Other Modeled Elements

In most cases, it is necessary to add supplemental modeled elements within the rendering software to aid in the visualization of BIM models. Both Enscape and Twinmotion have extensive catalogues of modeled elements that can be placed into the visualization model to serve this purpose. While these supplemental modeled elements can range from cars to people, there is one element that is common amongst almost all visualization projects: trees. Through adding trees to a visualization model, the BIM designer can add an extra layer of realism to the visualization while also creating a barrier to conceal the limits of the model from view. This section will focus on the process of inserting trees into a visualization model through both Enscape and Twinmotion, although this process can be utilized to incorporate any element from the catalogues that these software packages offer.

In Twinmotion, the process of adding trees to a given visualization model is fairly straightforward and efficient. The steps for incorporating trees into a Twinmotion model are as follows:

- *Step #1:* Once the desired BIM model has been loaded into Twinmotion through the plug-in, navigate to the populate tool and locate the "Trees" section within the model elements library.
- *Step #2:* In the populate tool, select the "Paint" option. This option will allow the user to select the desired tree models, select the diameter of their "brush", and then use their mouse to "paint" the trees onto the topographic surface. In the event the user only needs to place a single instance of the desired element, they can drag that element into the model space and drop it where it is needed.
- *Step #3:* Once the populate tool opens, drag all desired tree types from the model elements library into the appropriate location on the populate tool. The "Paint" feature will randomly place each of these tree types as the user clicks and drags on the topographic surface. By selecting more tree types, the brush will increase the density in which the trees are placed.
- *Step #4:* Define the diameter of the "brush" tool and then click and drag to "paint" the landscape with trees. In the event a mistake is made, switch to the "eraser" tool and click and drag over the trees you wish to remove. Continue to "paint" the landscape until all desired areas are filled with trees.

Figure 3.2.4.40: Instance of Twinmotion with Populate Tool Shown

In Enscape, the process for placing trees into a given visualization model is similar, although there are some key differences. For instance, while the Twinmotion model is separate from Revit and none of the incorporated elements will transfer to the original Revit model, Enscape will add any incorporated elements directly into the original Revit model. It is important to keep this in mind, because after clicking the "apply changes" button, Enscape will populate the any new confirmed elements into the model. If the placement of a large number of elements within the Enscape model is applied at the same time, the process for generating these elements within Revit can be very time consuming and resource intensive. For context, try to imagine thousands of trees populating in the Revit model space at the same time. To reduce the potential for performance issues or crashes, it is best practice to incrementally "apply changes" as new elements are placed, which will reduce the computing power required to complete the generation process. With this in mind, the steps for creating trees within Enscape are as follows:

- *Step #1:* Once the model is loaded into Enscape*,* open the asset library and type "tree" in the search bar at the top of the UI.
- *Step #2:* Select the "multi-asset placement" tool and then select the desired types of trees to be placed into the model by clicking on them in the asset library. Confirm the selection

by view the “selected assets” UI at the bottom of the screen. In the event that only a single element needs to be placed, the user can click and drag the element into the model space from the asset library.

- *Step #3:* Set the density of the placement and specify both a random distribution and rotation. This will place the trees in a more natural manner based on the density provided by the user.
- *Step #4:* Select the placement tool that best suits the area you wish to place your elements. The options for placement are rectangular, circular, and fill. The rectangular tool will place the selected assets within a rectangular area specified by the user, while the circular tool will place the selected assets within a circular area specified by the user. The fill tool will randomly distribute the selected assets across the entire selected surface.
- *Step #5:* Use the selected tool to populate the landscape with trees as desired. As mentioned previously, it is recommended to place trees and apply the changes incrementally to avoid long, resource intensive generation times. Continue this process until all desired areas are filled with trees.

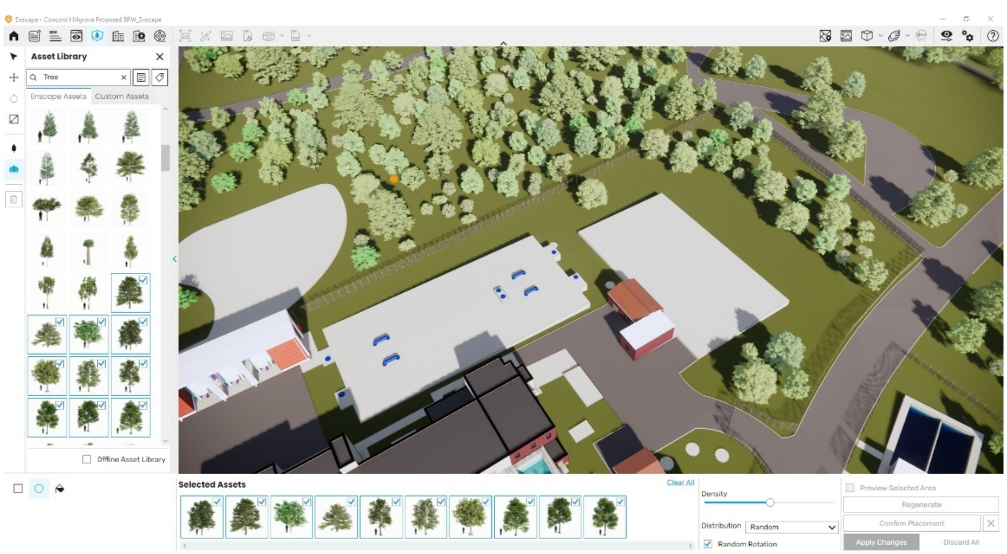

Figure 3.2.4.41: Enscape Asset Library and Mult-Asset Placement Tool

Applying Model Textures

In order to create visually stunning renderings of BIM models, the user must apply material textures to the surface of all elements within the model. These textures allow the user to better control the look of the visualization model and ensure that the digital model looks similar to its real-world counterpart. This process can be completed through multiple methods and the selection of a method depends solely on the rendering software that is being utilized to create the given visualization.

Twinmotion, for example, has a built-in material library that allows users to drag and drop textures onto the model's elements. These textures can be modified through multiple settings, which allows users to tweak the materials so that they closely resemble the selected material in the real world. The process of applying these material textures is very intuitive and allows the user to fully control the final visual quality of the model. The steps for completing this process are as follows:

- *Step #1:* In Twinmotion, navigate to the material library and find the desired material category. Once the material category is selected, the user will be able to choose from multiple textures that can be applied to their model's elements.
- *Step #2:* When a desired texture is located, the user can simply drag and drop the material onto the desired element within the model space. There are a few key settings to pay attention to when applying materials: replace material, apply to object, apply to selection. The replace material setting will replace the texture for all elements that are modeled with the given material. This is based on the materials applied within the Revit model during the modeling process. For instance, if the user utilizes the "replace material" setting to apply a brick texture to a brick wall, it will replace all brick textures

within the model with the applied texture. The “apply to object” setting will only apply the chosen texture to the element which it is dropped onto in the model space. This is useful for situations where only a single material texture needs to be modified. The “apply to selection” setting will apply the chosen texture to the current selection of elements within the model space. This is useful in instance where the user desires to modify a large number of textures without completely replacing the material for all elements within the model.

- *Step #3:* To further modify these material textures, the material settings can be adjusted to improve the overall quality of the applied texture. Some key settings that can be adjusted to add an extra level of realism to the model are grunge, scale, and roughness. The grunge setting will add a layer of dirt and dust to textures that are supposed to represent existing materials. The intensity of the grunge can be adjusted to dictate the amount of grime on each material texture. It is highly recommended to apply some level of grunge to all materials inserted into the model space, as even an exceptionally light layer can break up the repetitive patterns of the textures. The scale setting can be used to adjust the overall scale of the texture on the modeled element. In most cases, the textures seem to be inserted at a very small scale and this setting allows the user to increase the scale so that the material better reflects its real-world counterpart. Finally, the roughness setting allows users to dictate the reflectiveness of the applied texture. A lower roughness setting will produce a reflective or polished surface, while a higher roughness setting will produce a matte surface.

- *Step #4:* Continue this process until all materials are modified to reflect the desired textures. Through the completion of this process, the overall quality of the model visualization will be drastically improved.

Figure 3.2.4.42: Twinmotion's Material Library and Associated Settings

The process for applying material textures within Enscape differs slightly from that of Twinmotion. In Enscape, the textures applied to the BIM model in Revit through the modeling process are carried over into the imported model and cannot be modified within Enscape. This requires all necessary textures to be applied within the Revit model as opposed to the Enscape model. While this can limit the rapid editing and quality of material textures, Enscape offers a library of materials that can be downloaded for use through the Revit plug-in. By importing a given material into Revit, it will be available for use within Revit's material library. The process for applying materials within Revit for use in an Enscape model is as follows:

- *Step #1:* Within Revit, open the "type properties" menu for the element that the user wishes to modify.

- *Step #2:* Under the "construction" category in type parameters, click the edit button and find the material that needs to be modified. Hover the cursor over the material name and select the "…" button that appears.
- *Step #3:* Once Revit's material browser appears, navigate to the imported Enscape material and select it. Select apply and confirm any changes in each subsequential menu until all menus are closed. The material has now been successfully applied in Revit, thus applying it to the Enscape model.

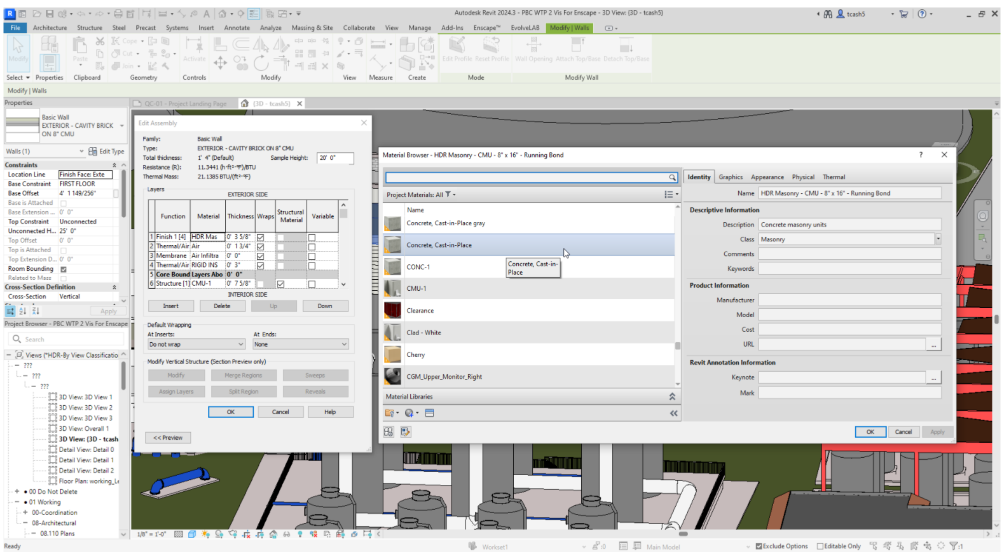

Figure 3.2.4.43: Revit Material Browser with Enscape Material Selected

Rendering Still Images

Some of the most common deliverables for visualization projects are rendered still images that the pursuit team can insert directly into their client presentation. In short, still images are non-dynamic images that are the simplest form of model visualization. Creating these images often involves carefully crafting the lighting, camera angles, and visual style in order to best represent the proposed project. In both rendering software packages, the process for creating these images is extremely simple and produces remarkable visualizations of BIM models in minutes.

In Twinmotion, the produced still images often take on a semi-realistic quality and, through the software's ray tracing capabilities, have a very visually appealing aesthetic. These images can be produced in mere minutes and the software makes it easy to batch render multiple images at once. In essence, batch rendering is when multiple images are created within Twinmotion then, through a selection menu, all of these are rendered at once and saved to the specified location on the computer's hard drive. This batch rendering process allows users to quickly create views and modify them as needed, without having to start from the beginning. With this concept in mind, the process for creating still image renderings in Twinmotion is as follows:

- *Step #1:* Within Twinmotion, enter "media mode" by opening the media menu at the bottom of the UI.
- *Step #2:* Position the camera in the model space at the desired angle, ensuring that the entire subject is within the view. Once the desired angle is achieved, click the "+" icon to add this view to the media menu.
- *Step #3:* When the created view is selected, the menu on the right-hand side of the UI will allow the user to update the environment, camera settings, rendering settings, and aesthetics of the image. Some of the most important settings to consider in this menu are the environmental settings. This will allow the user to manipulate the time of day, position of the sun, and weather conditions portrayed in the final image.
- *Step #4:* Repeat this process until all desired images have been created and modified, as necessary.
- *Step #5:* Navigate to the export menu within Twinmotion and add all images to the export session through the UI. After selecting the images to be exported, navigate to the bottom

of the export menu and run the export process. By completing this process, all of the created images will be rendered and saved in the specified location.

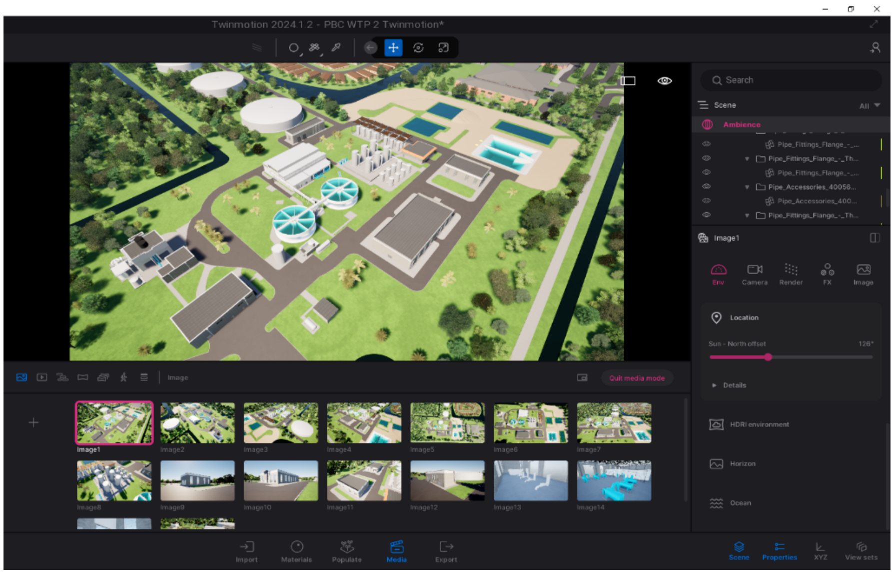

Figure 3.2.4.44: Twinmotion's Media Creation Menu

In Enscape, the process of rendering still images is simplified when compared to that of Twinmotion, although the quality of the final renderings is slightly reduced. The option for batch exports also exists, but this capability is slightly less optimized than its counterpart in Twinmotion. While Twinmotion allows for the rapid creation of view within its media menu, Enscape must generate any created views within the Revit model in order to unlock the capability for batch exporting. Therefore, it is less time consuming to render each view individually in Twinmotion and, in the event that an image must be re-rendered, recreate the view each time. The process for creating each of these renderings within Enscape is as follows:

- *Step #1:* Within Enscape, position the camera in the model space at the desired angle, ensuring that the entire subject is within the view.
- *Step #2:* Adjust the sun position by holding the shift key, right clicking, and then dragging the mouse either right or left as desired.

- *Step #3:* Once the desired aesthetic is achieved, navigate to the "screenshot" tool at the top of the UI and select it. Upon selection of this tool, the software will prompt the user to specify a file location for the rendered image to be saved and then the rendering process will automatically begin.
- *Step #4:* Repeat this process to create all of the necessary still image renderings.

Figure 3.2.4.45: Screenshot Tool Within Enscape

Rendering Section Cuts

In the visualization process, it is sometimes necessary to create rendered section cuts of a model in order to convey the design team's intent. Through these images, the pursuit team can provide a view of the interior of a structure, while also maintaining the site context around the building in the same image. These deliverables are fairly similar to the aforementioned still image deliverables, with the only difference being in the process of creating the section cuts within the given rendering software package.

When creating these section cuts within Twinmotion, the user must utilize the "section cube" from the library of assets within the software. Upon placement of this "section cube," it can be re-sized and re-positioned as needed to cut the required section in the given structure. From this point, the process for creating a rendered section image is identical to the process of creating renderings of still images in the previous section. Keep in mind that, since the “section cube” is an element that is physically present in the model space, it will need to be hidden in any created view where a section cut is not desired.

Figure 3.2.4.46: "Section Cube" Element Placed into Twinmotion Model

In Enscape, this process utilizes the “section box” tool from the “properties” menu within Revit’s UI. Begin this process by toggling the section box on in the 3D view that is being imported into Enscape and manipulating it to cut the desired section. Through toggling on the section box in Revit and creating the section cut in the imported 3D view, this will automatically create the section view in Enscape. From this point forward, this process is exactly the same as the process for creating renderings of still images within Enscape from the previous section.

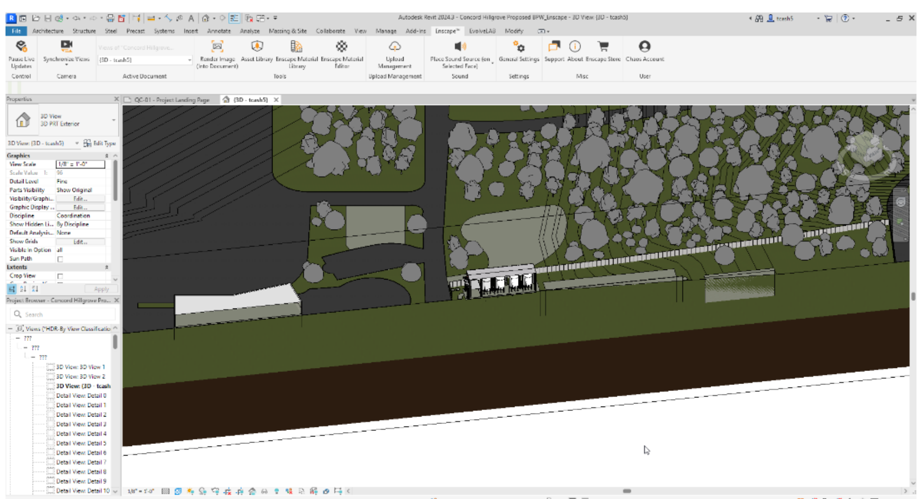

Figure 3.2.4.47: Section Box Created Within Revit

Rendering Videos

In visualization projects for pursuits, it is also common to develop rendered video deliverables to supplement the pursuit team's client presentation. Through the act of providing quality video representations of the proposed work, the pursuit team can set their presentation apart from the competition's presentation. This can also help provide context to the depth of thought and level of detail put into the proposed design. In both Twinmotion and Enscape, it is possible to develop high quality rendered video deliverables from a given BIM model in a short amount of time. As with most of the processes presented in this section, the process for creating these videos is similar on both software packages, although there are a few key differences.

Twinmotion can be used to create remarkably high fidelity rendered video clips and provides a consistent level of quality with each clip created. In summary, any video created in a rendering software relies on keyframes (a user defined camera angle at a given timestamp) to determine the camera's path of travel through the model. The environmental settings available within Twinmotion allows the user to manipulate the position of the sun, time of day, and weather in any given keyframe. In theory, this allows users to create timelapse videos that contain both changes in lighting and weather. For the purpose of this study, the focus will be on creating a simpler form of these videos and the lighting will only change to ensure that shadows within the model are not concealing any vital details. Keeping this in mind, the process for creating video visualizations in Twinmotion is as follows:

- *Step #1:* Through Twinmotion's media menu, navigate to the video creation feature. This menu is where the entire process of video creation takes place.
- *Step #2:* Position the camera within the model space at the desired angle and select the "+" icon to create a new video. Through selecting the "+" icon, this will set the first

keyframe at the current position of the camera. At the top of the created video, define the desired duration of the clip in the provided input area.

- *Step # 3:* Add multiple keyframes by selecting the “+” icon to the left or right of the previously inserted keyframe. Through selecting the “+” icon on the left, the new keyframe will come before the previous keyframe, while selecting the “+” icon on the right will insert the new keyframe after the previous keyframe. Continue this process until all keyframes are set and the path has been determined. To verify the quality of the determined path, the user can click the play button and watch a draft of the final video.
- *Step #4:* Manipulate the environment and FX settings as needed to set up the desired visual aesthetic. This can be done by selecting each keyframe individually and utilizing the settings menu that appears on the righthand side of the UI.
- *Step #5:* If a second video clip is desired within the same video, click the “” icon to add another clip. Repeat this process until all of the desired clips have been created.
- *Step #6:* Navigate to the export menu and select the created video to add it to the export batch. After the export process is complete, the final rendered video will be placed in the file location specified by the user.

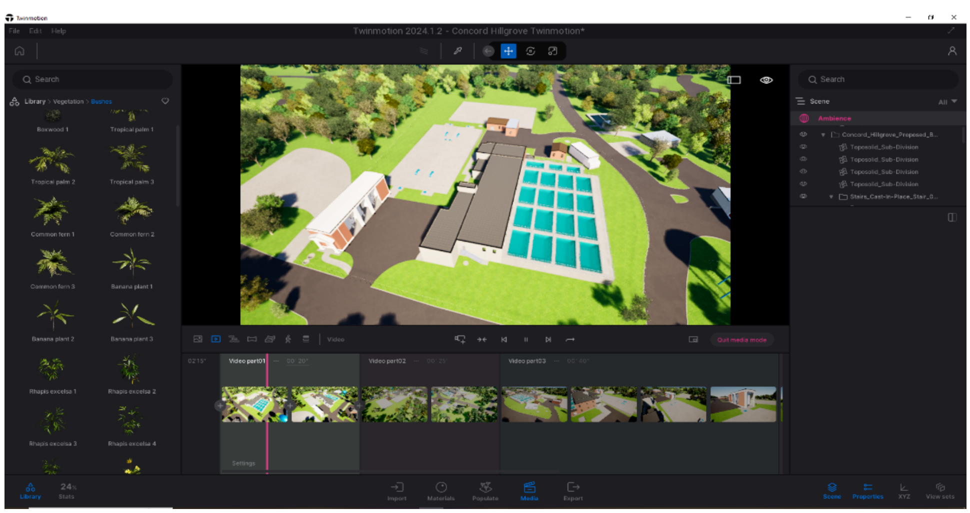

Figure 3.2.4.48: Twinmotion's Video Creation Menu

In Enscape, the process of creating rendered videos still relies heavily on the placement of keynotes, although the process differs slightly from that of Twinmotion. In a similar process to the process for creating still images in Enscape, each video clip must be exported as its own file due to the convoluted process for batch rendering within Enscape. In spite of this fact, the process for creating these video clips is extremely simple and the steps are as follows:

- *Step #1:* Launch the video editor within Enscape. This will cause a minimalistic menu to appear, which will prompt the user to input the desired duration of the clip and provide some options for camera movement. Experiment with the camera movement settings to determine which movement type best suits the desired final product.
- *Step #2:* Position the camera and hit the "+" icon on the right side of the UI to incorporate this camera position as the initial keyframe.
- *Step #3:* Similar to Twinmotion, Enscape allows users to insert new keyframes both before and after the previous keyframe by selecting the "+" icon on either side of the screen. Relocate the camera and create new keyframes until the desired video path is determined. To verify this video path, the play button can be used to play back a draft of the video prior to exporting it.
- *Step #4:* Export the video using the "export" button at the bottom of the screen. This will save the rendered video clip to the user defined location on the computer's hard drive. Repeat this process until all desired video clips are created. In the event that all clips need to be consolidated into a single video file, it is best to utilize video editing software to splice these clips together. Although not covered in this study, a free video editing program called DaVinci Resolve is highly recommended for completing this process.

Figure 3.2.4.49: Video Editor Feature Within Enscape

Executable Presentation Files and VR Environments

One of the most intriguing features within these rendering software packages is the ability to create executable presentation files. These executable files can be created in both Twinmotion and Enscape and can be opened by users without access to a license for the given software. In essence, these files open a viewer version of the software that allows users to view all of the created deliverables in a single location. This file provides a deliverable that allows clients to freely view the model and created deliverables on their own device. These files also offer access to an optimized VR experience that is compatible with most devices due to the viewer version's simplified nature. All of the executable presentation files and VR environments created for this study have been tested on an average quality computer running Windows 10 and a Meta Quest 2 VR headset.

In Twinmotion, the process of creating these executable presentation files is extremely simple and the user has the ability to select which of the deliverables created in prior sections will be viewable within the executable file. Therefore, the user can compile an effective presentation within the file and have complete control over what the client is seeing. Based on the tests conducted, the Twinmotion executable files run smoothly on an average computer by utilizing the medium-quality settings and the VR environment runs on the Meta Quest 2 with minor issues on the low-quality settings. One key issue to note is that the movement within the VR environment can feel clunky and non-intuitive at times. The process for creating these executable presentation files within Twinmotion is as follows:

- *Step #1:* Launch the media mode within Twinmotion and select the presentation feature. A menu will appear at the bottom of the UI prompting the user to specify which of the previously created deliverables will be utilized for the presentation. Keep in mind that, on top of these specified deliverables, the user will still be able to freely navigate the model space as desired within the final executable file.
- *Step #2:* Select the desired rendered images or videos to be added into the presentation by dragging and dropping them into the specified area.
- *Step #3:* After verifying that all desired deliverables are placed into the presentation, navigate to the export menu and export the file to the desired area on the computer's hard drive. This will create the executable file that can be launched by any user on any computer. As stated previously, this exe file also can be used to access a VR environment that is automatically created upon the creation of this file.

Figure 3.2.4.50: Image Showing Twinmotion Executable File Running

Figure 3.2.4.51: Image Showing VR Button Within Twinmotion EXE File

Figure 3.2.4.52: VR View Inside of Twinmotion EXE File

In Enscape, the executable file created during this process only yields a simplified version of the model that can be freely navigated by the user and a VR version of this environment. While it is unfortunate that all of the previously created deliverables cannot be bundled into this executable file, the simplified version created from the Enscape has many favorable upsides. While the visual quality of the model is lower than that of the Twinmotion executable, it runs considerably smoother on higher settings due to this same fact. The controls within VR seem to be very optimized and any individual with VR experience should be able to quickly become comfortable with the movement system. In both the model viewer and the VR viewer, a gamepad, such as an Xbox controller, can also be utilized as an option for movement. It seems that the executable files produced through Enscape are heavily focused on the end-user's experience and provides a lot of features to improve usability. These executable files can also be created by clicking a single button labeled "Export to EXE…" within Enscape and then allowing the file to generate. Therefore, due to the simple nature of this process, a step-by-step process is not necessary. Based on tests conducted for this study, the Enscape executable file runs exceptionally well on high settings on an average quality computer, while the VR environment runs smoothly on medium settings. In regard to the VR environment, the lack of issues present within the Enscape executable file also reduce the likelihood of VR sickness.

Figure 3.2.4.53: Image Showing Enscape EXE File Running

Figure 3.2.4.54: Image Showing Enscape EXE File's VR Settings

Figure 3.2.4.55: VR View Within Enscape EXE File

Live Walkthroughs

In many cases, a BIM designer will be asked to attend the pursuit interview or presentation in order to “pilot” the model in a live walkthrough. The intent of this process is to provide the owner with an all-encompassing view of the created visualization model, while also ensuring that someone with vast experience navigating the model space is in charge of the movement from point A to point B. Typically, in these walkthroughs the design team will present the features of the proposed work while the BIM designer focuses on navigating the model smoothly and efficiently. While both Enscape and Twinmotion can be utilized to conduct these live project walkthroughs, there are some key differences that must be considered when determining which software to use.

The most crucial factor to consider when determining which software to use for live model walkthroughs is performance. While in many cases Twinmotion provides a model visualization of higher visual quality, this can come with sacrifices in performance. On average computers, these performance issues can come in the form of lag or even complete freezes of the program. This problem is alleviated by the use of a powerful computer, but this is a crucial factor to consider. While Enscape typically produces model visualizations of a lower visual quality when compared to Twinmotion, this fact also lends itself to decreased potential for performance issues when running a model. Based on tests conducted for this study, Enscape can consistently run at higher settings than Twinmotion and has far less performance issues associated with its use.

Another key factor to consider when determining which software to use for these model walkthroughs is the final quality of the visualization model. As mentioned in abundance in prior sections, Twinmotion consistently outperforms Enscape in the quality of the final deliverables that are produced. Therefore, if a higher performance computer is available and the performance issues are alleviated, Twinmotion is highly recommended for live model walkthroughs. However, it is important to acknowledge that a majority of companies do not have an above average computer available. In this case, Enscape would be the recommended selection due to it decreased demand for a powerful computer.

Analysis of Specific Use Cases for Enscape and Twinmotion

Based on the research conducted within this section, the best rendering software solution for the creation of each visualization deliverable has been determined. When comparing these mediums for model visualization, it is important to consider the final visual quality of each deliverable, the time required to produce the given deliverables, and the performance of each rendering software package.

Through the research conducted, it has been determined that Twinmotion consistently provides deliverables of higher visual quality, while Enscape consistently has less performance issues. Therefore, in situations where the higher visual quality of the deliverable dictates the overall quality of the deliverable, Twinmotion is the correct selection.

The average times for all producing all desired deliverables within each software has also been determined through the creation of visualization deliverables for each case study utilizing both programs. Based on the data collected, that on average, it takes a BIM Designer approximately 4.125 hours to create all of the desired visualization deliverables within Twinmotion, while it takes the designer approximately 3 hours to create all of the desired visualization deliverables within Enscape. Through the time requirements above, it can be determined that it costs approximately $174.98 to produce a deliverable package in Twinmotion, while it costs approximately $127.26 to produce a similar package in Enscape (based on a labor burden rate of $42.42 per hour). While these costs and time requirements differ slightly, they are close enough to reduce the importance of the factors when choosing between these two software packages.

Based on the performance issues, or lack thereof, of each software, it can also be determined that Enscape is more applicable in situations where performance issues can lead to reduced deliverable quality or user discomfort.

Through consideration of these factors, each visualization deliverable was analyzed, and the best practice software selection was made each. The next page contains a table that provides an overview of each process, the renderings software package selected, and the reason that it was selected over the other software package:

Table 3.2.4.1: Best Practice Software Selection by Visualization Deliverable

Best Practice Software Selection by Visualization Deliverable		
Deliverable	**Selected Software**	**Reason for Selection**
Modeling Trees	Twinmotion	Twinmotion has a large selection of realistic trees, and the paint tool is extremely efficient for placing them quickly. When creating videos within Twinmotion, it is also best to use the trees within the program due to the fact that it automatically animates the trees when rendering a video.
Applying Materials	Twinmotion	Twinmotion's material library allows users to drag and drop realistic textures onto modeled elements. This allows the user to rapidly edit the material on any given element. Enscape pulls the material from the Revit model, which typically requires more modeling time to ensure the materials are correctly applied.
Rendering Still Images	Twinmotion	The quality of Twinmotion's rendered images is much higher than that of Enscape. The user also has much more control over the final look of the images.
Rendering Section Cuts	Enscape	Enscape allows the user to utilize Revit's section box to cut sections on their 3D view that is being imported into the rendering software. The model then automatically updates based on the section box placed into the model space. Twinmotion also requires some tweaking to make sure that the section looks visually appealing.
Rendering Videos	Twinmotion	Twinmotion allows for the creation of extremely high-quality videos through an extremely simple process. The user also has more control over elements such as sun position, weather, and time of day.
Executable File	Both	Either option is viable for producing executable presentation files. The selection of an option truly depends on the final use of the model and the specifications of the end-user's computer. In the event that the .exe is being used solely for visualization purposes on a stronger computer, use Twinmotion. In the event that the .exe is being used for VR applications or the end-user has a less powerful computer, use Enscape
VR Environment	Enscape	The VR experience offered by Enscape is more polished, user friendly, and less demanding on the user's computer. While the visual fidelity is higher on Twinmotion's VR engine, Enscape's engine is much more pleasant to use and is less likely to cause VR sickness.
Live Demonstration/Model Walkthrough	Enscape	Enscape utilizes less of the computer's resources and runs more smoothly than Twinmotion. Due to Twinmotion's visual fidelity, it is more prone to lag and other performance issues, which limits its capability for live demonstrations or walkthroughs.

It has been determined that, in most cases, a mix of both Enscape and Twinmotion are recommended in order to create deliverable packages for pursuit projects. Based on the proposed software selections from the table above, it would take a BIM designer approximately 4.08 hours to develop any given set of visualization deliverables. By utilizing the suggested software, on average, it would cost approximately $173.07 to produce a high-quality visualization deliverable package for any given BIM model. Therefore, the selected software packages will be utilized to develop their given visualization deliverables in the proposed "best practice" workflow.

3.2.5 INTERACTIVE PROJECT WALKTHROUGHS IN VR

As virtual reality technology improves and headsets become more widely available, many companies have begun exploring how that VR can be utilized to improve current workflows. One such way that AEC firms are applying this immerging technology is through interactive VR model coordination reviews. Two of the most effective ways of conducting these VR coordination reviews are the cloud-based applications Autodesk Workshop XR and Resolve BIM. In essence, both of these applications allow users to meet together within a virtual meeting room and then explore the model together in VR. These applications both utilize Autodesk Construction Cloud (ACC), which is a cloud service for hosting models and other design documents. After initial review, these applications are remarkably similar in terms of the quality of the experience, however they differ in the various features that each application offers. While the original purpose of these applications is for coordination review during the design stages, this technology has intriguing implications on the visualization of pursuit projects. The goal of this section is to determine if the VR model coordination review applications examined in this study are applicable towards pursuit projects in either a revolutionary or supplemental fashion. This section will contain a brief overview of each application and will aim to determine if either application offers features that are useful tools to aid in pursuit interviews.

Autodesk Workshop XR

Upon entering Autodesk Workshop XR on a VR headset, the user is greeted by a virtual meeting room with a workshop table in the center. This table is the space in which the selected BIM model will be imported by the users for review. An image of the virtual meeting space is provided below:

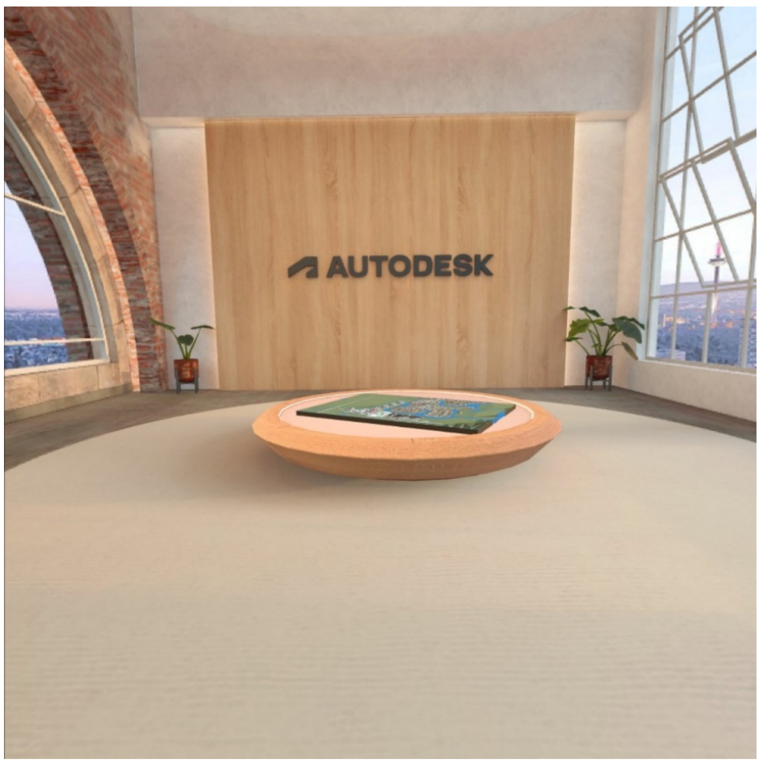

Figure 3.2.5.56: Autodesk Workshop XR's Virtual Meeting Space

From this area, multiple users can join the Workshop XR session and begin their virtual meeting. When other users join the area, they will appear as their Meta Quest avatar or one of Autodesk's default avatars. An example of a user's avatar appearance is provided in the image on the next page:

Figure 3.2.5.57: Meta Quest Avatar Within Workshop XR

Once the participants are ready to enter the model, they will approach the table and use the teleport feature to enter the model on the table. This feature requires the user to point at the desired location and then flick the thumb stick on the controller forward to initiate the teleport. A visual guide will then appear to confirm the teleportation location, and the user will release the stick to teleport into the model.

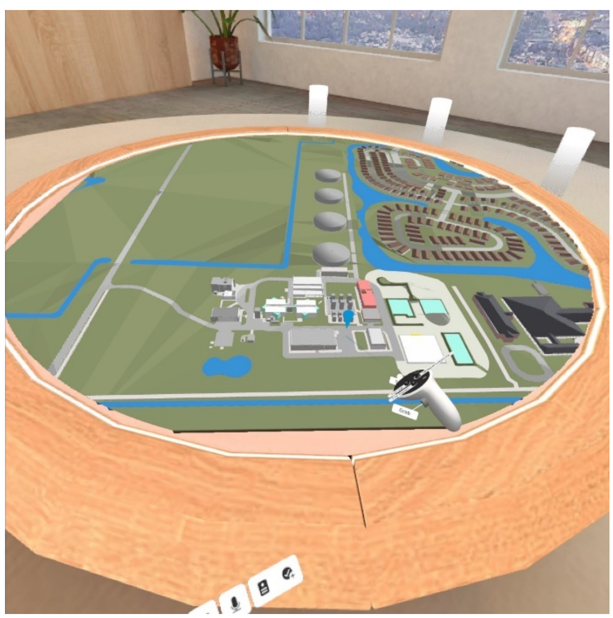
Figure 3.2.5.58: Workshop XR User Initiating Teleportation

Once the participants are gathered within the model, they are free to explore the different areas of the model as needed. Typically, this environment is utilized to immerse users in order to notice design flaws or clashes within the model. Through the UI, users have the ability to take measurements, gather participants in a certain area, create coordination issues that are uploaded directly to ACC, or inspect the properties of a given element.

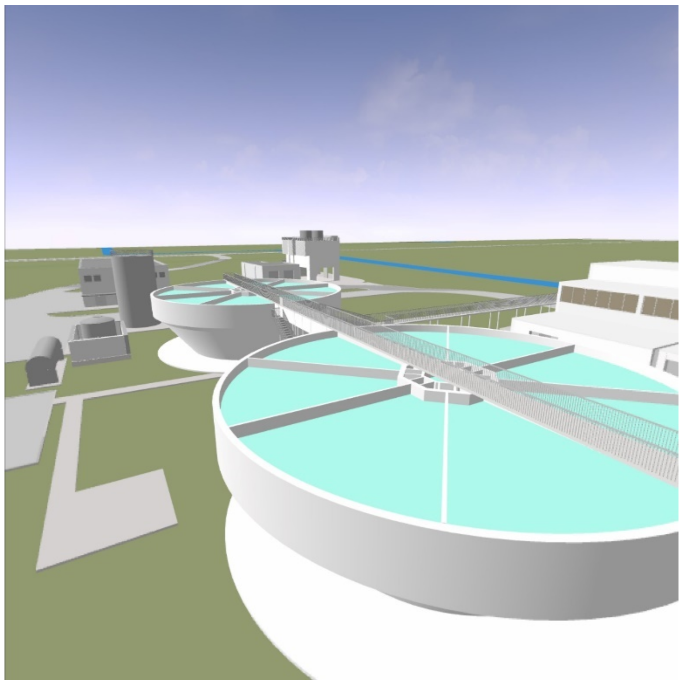

Figure 3.2.5.59: Image of User's View Within Workshop XR

As the meeting concludes, all users will navigate to the “exit workshop” button on their UI and simply exit the meeting. If the need arises, the users can quickly reconvene at a later time to continue or expand upon the meeting by re-entering the Workshop XR session.

At the submission of this paper, Autodesk Workshop XR has only recently been released to Autodesk AEC Collection members. All tests conducted throughout this study were conducted on a premium trial version of Autodesk Workshop XR where all features were available. While this application is in its infancy, it displays exciting potential for model management, design coordination, and presentation tasks. As new features continue to be developed, this application will become a quite common tool used amongst BIM designers and design teams.

Resolve BIM

The user experience in Resolve BIM is similar to that of Autodesk Workshop XR, although there are a few differing features, and the UI is slightly different. A Resolve BIM session begins by inserting the user directly into the model at a predetermined point. For the sake of the trial, this predetermined point is an equipment room in an industrial facility. This initial loading point is pictured below:

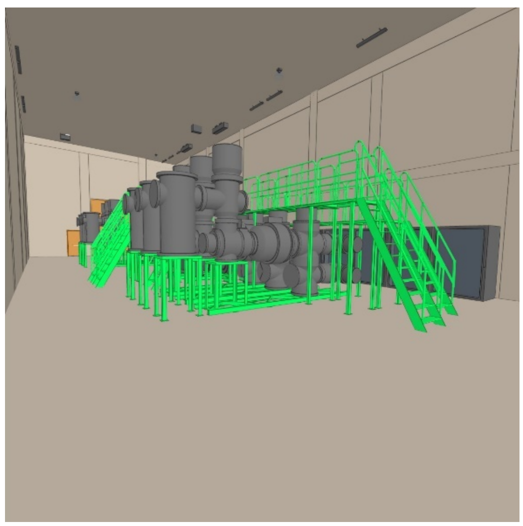

Figure 3.2.5.60: User's Initial View in Resolve BIM

Figure 3.2.5.61: Control Panel Within Resolve BIM

After all participants have loaded into the model, the virtual meeting can begin. Unlike Autodesk Workshop XR, there is not a virtual meeting room area, although users can exit the model and join a “dollhouse” view of the entire model that serves a similar purpose. From this area, the users can view the model at scale and even create section cuts to better inspect the modeled elements. An image of this “dollhouse” view is provided below:

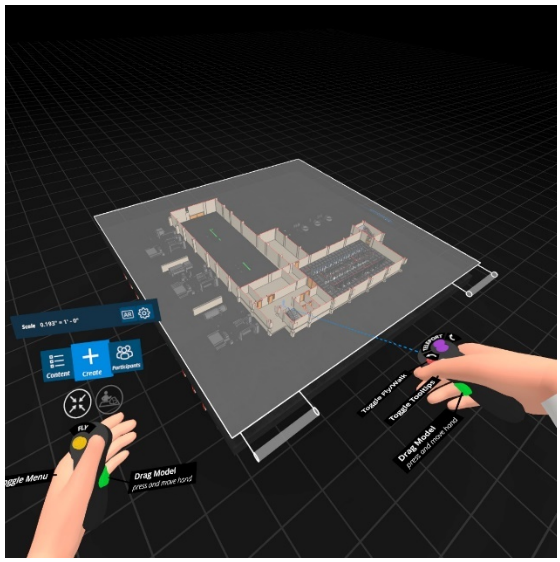

Figure 3.2.5.62: "Dollhouse" View Within Resolve BIM

From the “dollhouse” view, users can point to specific areas within the model and initiate a teleport into it by pointing and flicking their right thumb stick forward. When the user is ready to be teleported into the model, they just need to release the thumb stick, and they will then be inserted into the model. By utilizing the available smooth motion or teleportation controls, the user can then navigate the model freely. While within the model, the user has access to multiple annotation tools, such as measurement tools, sketch tools, view creation tools, and text annotation tools. The tools offered show promise in aiding design teams’ ability to coordinate on issues, develop new concepts, or communicate within the model. To access their toolbox, users must select the “create” menu on their UI. From this point, the user is free to select the tool that best suits their needs. An image of the available toolbox is provided on the next page:

Figure 3.2.5.63: Annotation Menu Within Resolve BIM

While this application is not an official Autodesk product, it provides users with the ability to link their BIM 360 or ACC cloud models into the application for review. Unfortunately, due to the fact that the software is not an official product of Autodesk, no markups or annotations have the capability of synchronizing to the standard web version of ACC or BIM 360.

Despite this fact, this application also shows potential for improving model management workflows, design coordination, and model review meetings. While, like Autodesk Workshop XR, Resolve BIM is still in the development process, it has the potential to revolutionize many of these mundane workflows in the future as the application develops.

Analysis of Interactive Project Walkthrough Workflows

In regard to pursuit projects, these virtual meeting environments offered by each application provide intriguing locations in which a design team could conduct portions of a pursuit interview. This would theoretically allow the design team to lead the potential client around the proposed design at a 1:1 scale within the VR environment. If implemented correctly, Autodesk Workshop XR could potentially allow AEC firms to separate themselves from their competitors by creating a certain “wow” factor during their pursuit interview. However, it can be concluded that, although extremely intriguing, limiting factors such as VR hesitancy amongst some individuals within the AEC industry and the requirement of each individual present in the interview to have access to a VR headset makes this workflow difficult to implement at the current time. Despite this conclusion, as this technology becomes cheaper and continues to become more widely accepted by the working population, these applications could become utilized in many workflows outside of model coordination amongst the design team. The VR industry is already making strides toward reducing the cost required to implement VR technology, with headsets such as the Meta Quest 3S that has a retail price of approximately $300. While these applications will not currently be incorporated into the "best practice" workflow proposed by this research, as the aforementioned limiting factors are alleviated, there is substantial potential for that to change in the near future.

3.2.6 IMAGE-TO-VIDEO AI MODELS FOR VISUALIZATION

One of the largest inspirations for this study was the onset of impressive image-to-video AI models that produce stunning videos based on user input. A conversation with a colleague posed an exciting research question, "Will image-to-video AI models replace the need for the creation of traditional BIM visualization models in the pursuit phase?" While it is implausible that it will replace BIM visualization in the near future, it is important to adapt to this innovative technology as it matures in order to avoid becoming obsolete. By utilizing AI as a tool, BIM designers can become the guiding hand for creating these AI visualizations before this becomes standard practice in the AEC industry.

With the rapid growth of AI and AI related technology, it is important to understand the capabilities that it possesses and how it can be utilized to improve existing workflows without removing the need for a guiding hand. While AI is capable of impressive feats, there is a certain quality control aspect that will always require human intervention. The important idea to keep in mind regarding artificial intelligence is that it is a tool not an all-encompassing replacement for the existing workforce. Just as with any tool, it will improve productivity and increase the level of quality demanded on any given project. For example, with the introduction of CAD software, this revolutionized jobs in the AEC industry. A plan set that once took hundreds of people hundreds of hours to draw by hand in drafting rooms could now be drafted in a fraction of the time. The same principle exists on a larger scale with AI technology.

This is why it is imperative to explore the applications and implications of AI technology on the AEC industry, especially regarding pursuit projects. Due to the creative nature of model visualization, these AI technologies have immense potential to improve productivity in existing workflows. This study has already touched on the capabilities of AI image generators, such as EvolveLAB's Veras, and the implications that these models have on the BIM visualization process. To take this research a step further, this work will also explore the implications of AI image-to-video models on the creation of visualization deliverable packages. The goal of this research is to determine the efficacy of an image-to-video model, Runway ML, by creating visualizations from low level of detail (LLOD) AI images, high level of detail (HLOD) AI images, and high level of detail (HLOD) model images.

Process of Creating AI Videos from Images

To fully understand the power of Runway ML as an image-to-video generator, one must first understand the simplicity of the process required to create these AI videos. Runway ML requires users to import their desired images and then, through natural language prompting (NLP), the user must describe the desired video. This description can include details about the subject, camera movement instructions, and a description of the desired aesthetic. The step-by-step process is provided below for context:

- *Step #1:* Launch Runway ML in a web browser and create a new session. This new session will prompt the user to select an AI model to utilize for the generation of the video. For this study, all images were generated using Gen-3 Alpha Turbo, which is a diffusion model.

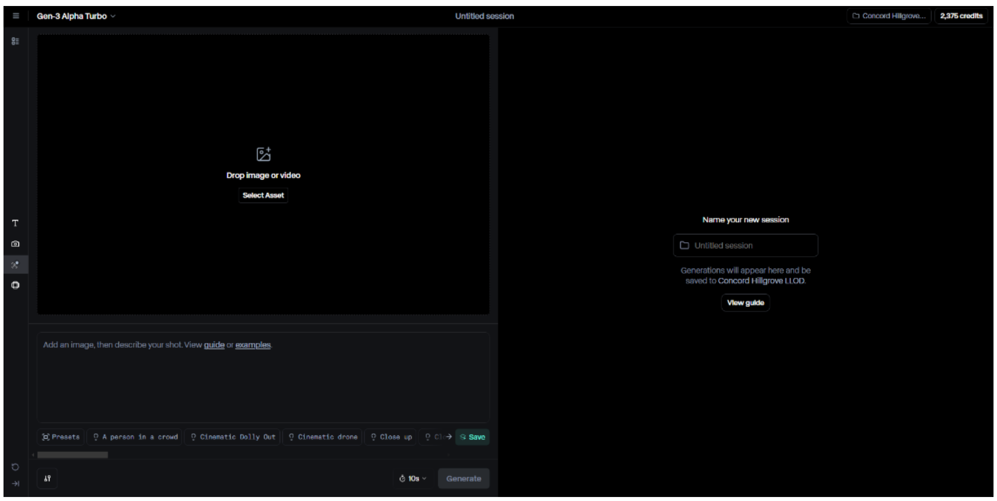

Figure 3.2.6.64: Image of a New Runway ML Session

- *Step #2:* Upload an image to utilize as a basis for the video generation. In the case where a user desires to utilize multiple images as keyframes, this is possible by inserting more images through the prompts that appear on the UI

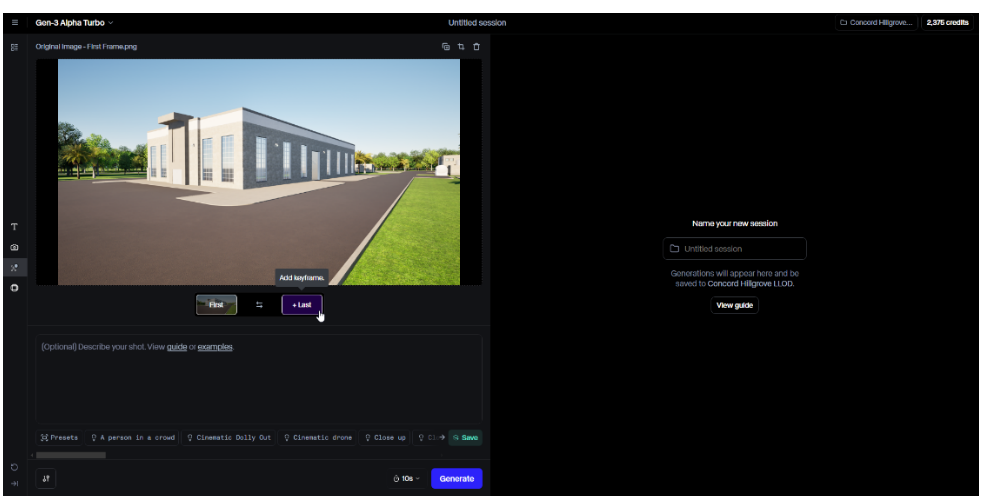

Figure 3.2.6.65: Image Showing Asset Selection Process in Runway ML

- *Step #3:* Begin to prompt the AI through NLP. This will allow the user to dictate the desired generation to the AI model. For this study, a common initial prompt was utilized in order to create AI videos of proposed structures on the model. This prompt read, “The camera slowly pulls back from a [description of building or structure] on a water treatment plant. A stunning establishing shot is revealed.”

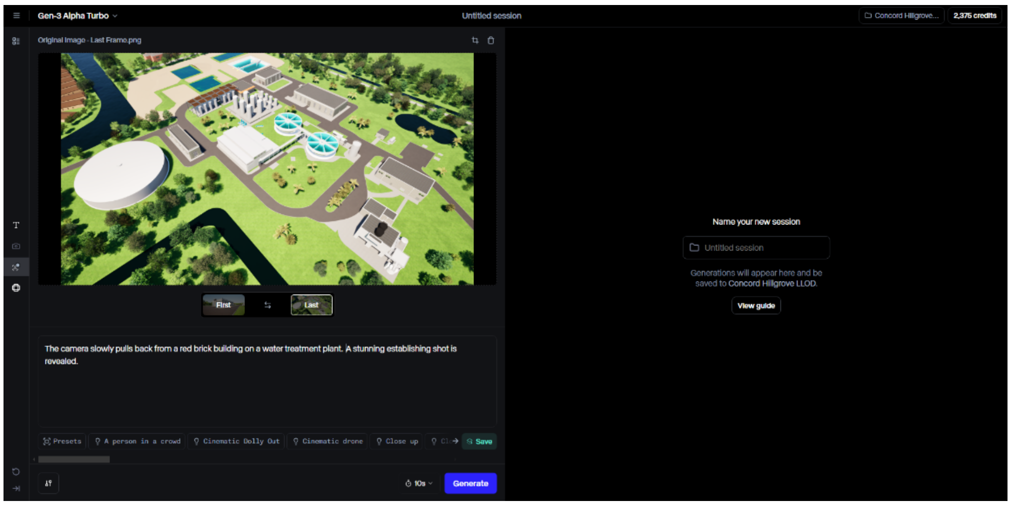

Figure 3.2.6.66: Prompting Process in Runway ML

- *Step #3:* Review the generated video and re-prompt if needed. The user can review the video generated on the right side of the UI for any inconsistencies. In the event that the video is not close to the desired outcome or has strange generations within the image, it would be advised to further describe the desired outcome through re-prompting. If the image is close to the desired outcome, the user can either re-run the same prompt or edit the desired video. It should be noted that, as with most AI image or video generation models, it will take some trial and error to develop the desired image.
- *Step #4:* After multiple iterations are generated, the user will have the ability to review the initial prompt for each video and the generated footage. The user can then download the best results onto their local hard drive, as necessary. An image of a session populated with multiple iterations is provided on the next page (note the download option at the top of each image):

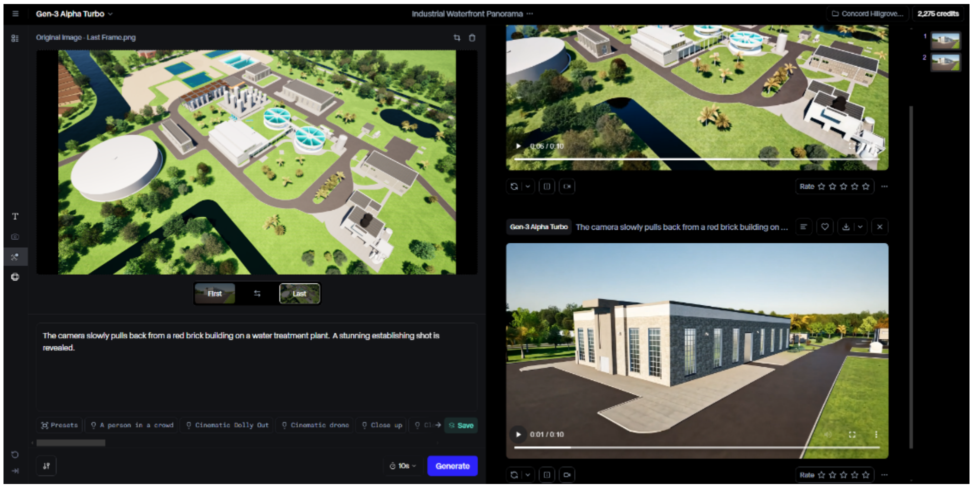

Figure 3.2.6.67: Runway ML Session Populated with Iterations

Low Level of Detail AI Rendered Image Results

Through conducting experiments on LLOD AI images with Runway ML, it was determined that the AI model was effective at consistently producing useful ten second video clips. On average, the process of generating these video clips took approximately 15 minutes and the results were impressive based on the lack of detail in the image. An example of the original image and a still image from the generated video clip is provide below (note that everything outside of the original image is generated by Runway ML):

Figure 3.2.6.68: Original LLOD AI Image Provided to Runway ML

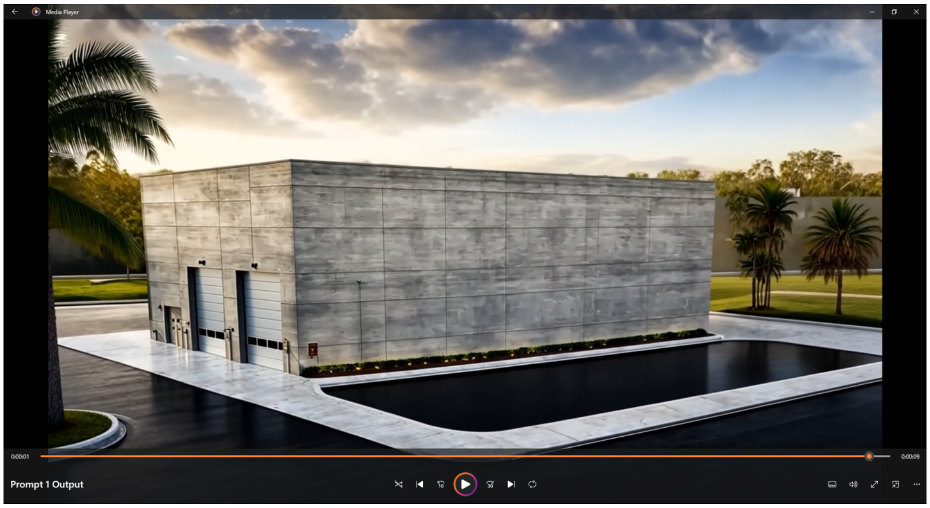

Figure 3.2.6.69: Video Clip Resulting from LLOD AI Image

High Level of Detail AI Rendered Image Results

The same process was applied to AI images that were developed using the high level of detail BIM model. This process determined that Runway ML was also extremely effective at producing highly detailed ten second video clips. On average, the iterative process of developing videos generated with the HLOD AI images takes around 10 minutes to complete. An example of the original image and a still image from the generated video clip is provide below (note that everything outside of the original image is generated by Runway ML):


Figure 3.2.6.70: Original HLOD Image Provided to Runway ML

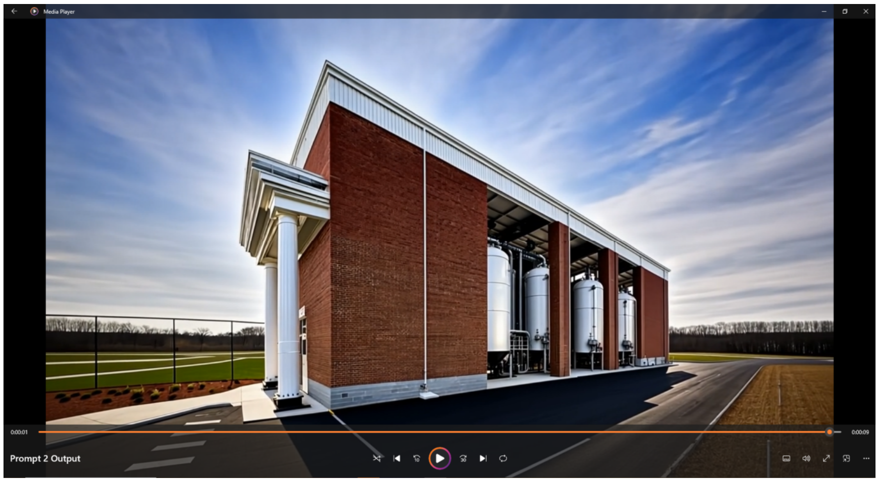

Figure 3.2.6.71: Video Clip Resulting from HLOD AI Image

High Level of Detail Rendered Model Image Results

This process was also applied to images created with traditional visualization techniques on a HLOD model. The process determined that given the correct angle of a proposed structure, Runway ML is relatively effective at creating ten second video clips from these images. Unfortunately, the elevated level of detail provided by these images can cause issues if the image does not provide enough information for the AI model to correctly infer the generated elements. On average, this process requires approximately 10 minutes to complete and has acceptable results a majority of the time. An example of the original image and a still image from the generated video clip are provided below:

Figure 3.2.6.72: Original HLOD Model Image Provided to Runway ML

Figure 3.2.6.73: Video Clip Resulting from HLOD Model Image

Analysis of Runway ML's Visualization Capabilities

Based on the experiments conducted within this section, it could be determined that Runway ML is effective at creating short video clips from a single image, regardless of LOD. Although, the model strives when provided with the proper high LOD information. On average, these HLOD images, regardless of type, can produce a quality video clip in approximately 10 minutes, while the LLOD AI image take approximately 15 minutes. The images produced definitively are more applicable to a conceptual stage, thus making this workflow effective in the pursuit phase of projects. Runway ML offers valid solutions in project circumstances that do not provide enough time to generate detailed models, in cases where there is not time to produce standard visualizations with typical workflows, and also in situations where supplemental presentation materials are required to complete client presentations. As image-to-video AI technology progresses, this could eventually overtake traditional methods of model visualization for all circumstances. However, at the current state, Runway ML's largest benefit is expediting visualization creation in situations that lack the proper time to develop a model further and allow for sacrifice of accuracy.

3.2.7 PROPOSED "BEST PRACTICE" WORKFLOW FOR SPECIFIC USE CASES

Through the development of this study, it became evident that the "best practice" workflow proposed would be heavily reliant on the circumstances of any given project. Therefore, the proposed "best practice" workflow will consist of two differing processes that fully depend on the constraints placed upon the project. For example, a "best practice" solution for a project with average budget requirements will differ heavily from that of a project with demanding budget requirements. It should be noted that the aforementioned budget requirements refer to both budgeted monetary requirements and budgeted time requirements. This section will aim to detail the specific use cases for each process of the proposed "best practice" workflow, while also providing an outline of the traditional workflow based on average project requirements.

In order to best evaluate these processes, two case studies have been developed (detailed in succeeding subchapters 3.3 and 3.4). The first of these case studies, Palm Beach County Water Treatment Plant No. 2, will be utilized to evaluate the performance of the best practice workflow on a large-scale project with average requirements and provide a comparison to the existing workflow. The second of these case studies, Concord Hillgrove Granular Activated Carbon Upgrade, will focus on comparing the results of the "best practice" processes for both projects of average and demanding requirements.

"Best Practice" Process with Average Project Requirements

For projects with both average time and budget constraints, it is imperative that the focus of the proposed process is the development of the highest quality visualization deliverable package in the shortest amount of time. Therefore, in some cases, the examined method with the highest quality was chosen over methods with lower time requirements. The goal of this process is to reduce both the time and cost of the traditional workflow, while also maintaining or surpassing the original quality. It would be recommended to use this process in situations where the BIM designer has around 2 weeks to complete the deliverable package and a typical monetary budget. This process allows for the creation of supplemental deliverables if they are required by the project team and the allotted time permits their creation. The proposed "best practice" process for developing pursuit deliverable packages with an average project requirements is provided below:

Table 3.2.7.1: Best Practice Process with Average Project Requirements

"Best Practice" Process with Average Project Requirements			
Step	**Task**	**Method**	**Avg. Time Requirement (Hrs.)**
1	Topographic Surface Creation	CAD Mapper	4.880
2	Existing/Proposed Equipment Modeling	Parametric Family Library	1.000
3	Development of Proposed Structures in Revit	High LOD Development	7.000
4	Miscellaneous Revit Modeling Tasks	Traditional Modeling	58.630
5	Developing Visualization Models	Twinmotion	2.290
6	Creating Rendered Still Images	Twinmotion	0.540
7	Rendered Section Cuts	Enscape	0.208
8	Rendered Videos	Twinmotion	0.625
		Avg. Required Total Time	**75.173**
9	Executable Project Files **If required**	Twinmotion/Enscape	0.333
10	VR Environments **If required**	Enscape	0.083
11	Live Model Demonstrations/Walkthroughs **If required**	Enscape	N/A
12	Supplemental Image/Video Generation **If required**	EvolveLAB's Veras/Runway ML	2.788
		Avg. Supplemental Total Time	**3.20**
		Avg. Total Time	**78.38**

"Best Practice" Process with Demanding Project Requirements

For projects with either below average time or budget constraints, it is imperative that the focus of the proposed process is the rapid development of a deliverable package at an accepted reduction of quality. Therefore, in some cases, this process will favor solutions that offer considerable time reductions, while sacrificing some of the final quality. The goal of this process is to provide pursuit teams with an innovative solution when the time or monetary budget constraints are not in their favor. It would be recommended that this process only be utilized in circumstances where the visualization deliverables must be developed in under a week or the overall risk of losing the pursuit is high. This process offers a low risk, high reward solution through the exponential time savings that it provides, and the lack of resources required. The proposed "best practice" process for developing pursuit deliverable packages with a demanding project requirements is provided below:

Table 3.2.7.2: Best Practice Process with Demanding Project Requirements

"Best Practice" Process with Demanding Project Requirements			
Step	**Task**	**Method**	**Avg. Time Requirement (Hrs.)**
1	Topographic Surface Creation	CAD Mapper	4.880
2	Existing/Proposed Equipment Modeling	Parametric Family Library	1.000
3	Development of Proposed Structures in Revit	Low LOD Development	0.540
4	Miscellaneous Revit Modeling Tasks	Traditional Modeling (Low LOD)	7.500
5	Creating Rendered Still Images	EvolveLAB's Veras	2.080
6	Rendered Videos	Runway ML	0.333
7	Live Model Demonstrations/Walkthroughs **If required**	Enscape	N/A
		Avg. Total Time	**16.33**

Traditional Workflow with Average Project Requirements

For comparison, it is important to outline the traditional workflow for creating visualization deliverable packages for pursuit projects. This process utilizes a combination of the Google Earth method for topographic surface creation, traditional modeling methods for all modeling tasks, and only utilizes one visualization platform for all deliverables. In the event that it is required, any live model demonstration is conducted in Enscape due to its reduced potential for performance issues. The traditional workflow places a heavy emphasis on creating deliverables of the highest quality. Based on the current workflow's extensive time requirements, this workflow often causes BIM designers to turn down pursuit opportunities related to projects with demanding requirements. The existing workflow for developing pursuit deliverable packages with average project requirements is provided below:

Table 3.2.7.3: Traditional Workflow with Average Project Requirements

Traditional Workflow with Average Project Requirements			
Step	**Task**	**Method**	**Avg. Time Requirement (Hrs.)**
1	Topographic Surface Creation	Google Earth	17.00
2	Existing/Proposed Equipment Modeling	Traditional Family Creation	5.60
3	Development of Proposed Structures in Revit	High LOD Development	7.00
4	Miscellaneous Revit Modeling Tasks	Traditional Modeling	58.63
5	Developing Visualization Models	Twinmotion	2.29
6	Creating Rendered Still Images	Twinmotion	0.54
7	Rendered Section Cuts	Twinmotion	0.25
8	Rendered Videos	Twinmotion	0.63
		Avg. Required Total Time	**91.93**
9	Executable Project Files **If required**	Twinmotion	0.333
10	VR Environments **If required**	Twinmotion	0.083
11	Live Model Demonstrations/Walkthroughs **If required**	Enscape	N/A
12	Supplemental Image/Video Generation **If required**	Twinmotion	1.165
		Avg. Required Total Time	**1.58**
		Avg. Total Time	**93.51**

Initial Analysis of the Proposed "Best Practice" Workflow

Based on the data collected throughout the development of the "best practice" workflow, it can be estimated that both of the proposed processes will result in a wide range of benefits. Both of the proposed processes offer benefits in time reduction, cost reduction, and quality preservation.

In the case of the proposed process for projects with average requirements, there is actually potential for an increase in quality due to the greatly reduced time requirements. Through analysis of the data collected, it was determined that, when compared to the traditional workflow, the best practice process for average projects reduced the time required by approximately 15.13 hours, on average. When comparing the average cost of the traditional method ($3,966.76) to the cost of the proposed process ($3,324.78), this represents an average cost reduction of $641.81 (based on a labor burden rate of $42.42/hr) when using the "best practice" workflow, in lieu of the traditional workflow. This average cost reduction and the reduction of the time requirements alone provide promising evidence that the "best practice" workflow is an overall improvement upon the traditional workflow.

It can also be determined that when utilizing the proposed process for projects with demanding requirements, there is an average completion time of approximately 16.33 hours. Therefore, projects completed utilizing this process of the proposed "best practice" workflow only require approximately $692.72 to complete the pursuit deliverable package. These limited cost and time requirements allow BIM designers to create a viable deliverable package within constraints that would have once rendered this task impossible. This fact alone will decrease the amount of demanding pursuit projects that are not taken on by BIM designers due to their insurmountable constraints, albeit the given pursuit team must accept the slight reduction in overall quality.

3.3 CASE STUDY NO. 1

The first case study developed for this research was conducted on a previously completed project, Palm Beach County Water Treatment Plant 2. This project was originally completed utilizing the traditional workflow in January of 2024. Based on the original requirements, this would be considered a large-scale visualization project with average requirements. Therefore, in this case study, the results of the "best practice" workflow for projects with average requirements will be compared to the initial results of the traditional workflow. The goal will be to provide both qualitative and quantitative data that further supports the use of the proposed "best practice" workflow, while also improving the resulting deliverable package. This section will break down the original scope, baseline information provided, original project requirements, desired deliverable package, and the purpose of this case study.

Scope & Baseline Information Provided

At the onset of this project, an initial project scope and some key baseline information was provided to the BIM designer by the project pursuit team. The scope of this project consisted of the following work items:

- Design of a proposed nanofiltration filter facility
- Design of a proposed generator building
- Design of a proposed high service pump station (HSPS)
- Design of an expansion to the existing chemical storage area
- Design of a proposed odor control (OC) scrubber and degassifier structure
- Design of a proposed lime softener
- Design of three proposed 5 MGD storage tanks
- Design of all appurtenances or process changes related to proposed work items

- Demolition of obsolete lime softener
- Demolition of existing 3 MGD storage tank

Through initial estimates, it was proposed that the effort associated with developing a visualization package of all elements associated with the scope above would take approximately 120 hours to complete. From this point, key baseline design information was provided to the BIM designer by the pursuit team's project manager. This baseline information consisted of a general proposed site arrangement, the site address, a detailed list of required equipment and associated manufacturers, a general description of improvements, dimensions of proposed structures, the desire for an elevated level of detail, and the desire for a semi-realistic aesthetic.

Original Project Deliverable Requirements with Traditional Workflow

Based on the traditional workflow, it was determined that the following deliverables could be developed at a high quality within the required 120 hours:

- A high LOD BIM model and associated visualization model
- Rendered still images of overall site
- Rendered still images of major proposed structures
- Rendered videos showcasing the proposed work package
- A live model demonstration

Desired Deliverable Package for Case Study

Through utilization of the "best practice" workflow, it is desired to complete and expand upon the aforementioned deliverable package for this case study. The time reduction provided by the proposed "best practice" workflow will allow for the creation of extra deliverables within the same 120-hour period. The supplemental deliverables desired for this case study are as follows:

- An executable presentation file

- A single-user VR Environment
- Supplemental AI images of proposed work
- Supplemental AI videos of proposed work

Purpose of Case Study

The overall purpose of this case study is to provide both a quantitative and qualitative comparison of the existing and proposed "best practice" workflow. Through the work completed in this study, the overall time reduction and benefit of the proposed "best practice" workflow will be determined. This case study will also provide an example of the increased quality of the final deliverable package that can be credited to the time reduction provided through the proposed workflow. In theory, the reduction of time requirement allows BIM designers to focus more on the number of details in the BIM model rather than monotonous modeling tasks. Overall, this case study will provide conclusive evidence of the overall efficiency of the proposed "best practice" workflow.

3.4 CASE STUDY NO. 2

The second case study developed for this research was conducted on an upcoming pursuit project, Concord Hillgrove Water Treatment Plant Granular Activated Carbon (GAC) Upgrade. This proposal interview will take place in the coming months and the "best practice" workflow will be utilized to develop the visualization deliverable package. Based on the project requirements, this would be considered a small-scale visualization project with average requirements. Although, for the sake of this research, two deliverable packages will be developed for this project, assuming both average and demanding requirements. The goal of this case study is to provide both quantitative and qualitative data for each of the proposed processes of the "best practice" workflow. Through utilizing these processes on a new project and comparing the results to the initial estimate developed assuming the use of the traditional workflow, this case study will aid in validating the effectiveness of the proposed "best practice" workflow at various levels of project demand.

Scope and Baseline Information Provided

Through initial discussions of this project, a general project scope and some key baseline information have been provided to the BIM designer by the project pursuit team. The scope of this project consists of the following work items:

- Design of a proposed building containing new GAC contactors
- Design of a proposed in-ground precast pump station and associated manhole
- Design of all appurtenances and process changes associated with proposed work
- Demolition of existing unused storage building
- Demolition and replacement of existing parking lot in affected areas

Through initial estimates, it was proposed that the effort associated with developing a visualization package of all elements associated with the scope above would take approximately 80 hours to complete using the traditional workflow. After this estimate was provided, the project pursuit manager provided the BIM designer with key baseline design information. This baseline information consisted of a general proposed site arrangement, the site address, a detailed list of required equipment, images of proposed GAC contactors, a general description of improvements, dimensions of proposed structures, the desire for an average level of detail, and the desire for a semi-realistic aesthetic.

Desired Deliverable Package for Case Study: Average Requirements

Based on initial conversations with the pursuit team, it was determined that the following deliverables could be developed at a high quality within the required 80 hours by utilizing the "best practice" process for projects with average requirements:

- A high LOD BIM model and associated visualization model
- Rendered still images of overall site
- Rendered still images of major proposed structures
- Rendered videos showcasing the proposed work package
- A live model demonstration
- An executable presentation file
- A single-user VR Environment
- Supplemental AI images and Videos of proposed work

Desired Deliverable Package for Case Study: Demanding Requirements

In the hypothetical scenario that this project must be completed utilizing either a limited monetary budget or heavy time constraints, this would significantly alter the final visualization deliverable package. In the favor of producing a visualization package in the shortest amount of time possible, this package would contain the follow deliverables:

- A low LOD BIM model
- AI image of proposed work
- AI video of proposed work
- A live model demonstration

Purpose of Case Study

The overall purpose of this case study is to provide both a quantitative and qualitative regarding both processes of the proposed "best practice" workflow. This case study will provide examples of the application of each specific use case based on project demand, while also aiming to provide the highest quality possible. Through the average requirement deliverable package, this study will compare the time of completion and final cost to that of the estimate developed on the basis of the traditional workflow. This provides another performance indicator that allows researchers to gauge the effectiveness of the proposed workflow. Through the demanding requirement deliverable package, this study will provide conclusive evidence on the overall efficacy of AI models in producing expedited deliverable packages in circumstances where this is deemed necessary. By virtue of exploring both avenues, the data collected in this case study will be used to determine the level of success this research achieved in producing a truly efficient "best practice" workflow for the creation of visualization deliverables for pursuit projects.

3.5 CONCLUSION

Throughout the course of this chapter, the research methodology that was utilized to develop the proposed "best practice" workflow was provided in strenuous detail. At the onset of the chapter, six key research questions were posed regarding key processes in model visualization that showed room for improvement. These research questions focused on the improvement of modeling techniques, the selection of proper solutions depending on project circumstances, and the ability of AI diffusion models to assist in the creation of key deliverables. This methodology also explored innovative ways to present pursuit projects to clients through both single-user and multi-user collaborative VR environments. As a part of the research methodology, an in-depth overview of the conducted research provided readers with insight into the selection process of key workflow elements and justification of the final selection for the proposed "best practice" workflow. This methodology chapter also provided step-by-step instructions for utilizing each of the proposed solutions to allow for future researchers or BIM professionals to recreate the key processes of proposed “best practice” workflow for their own work.

After conducting the initial research, a “best practice” workflow was provided, and specific use cases were established. These specific use cases necessitated the need for the proposal of two differing processes based on the constraints placed upon the project. The processes proposed represent solutions for both pursuit projects with average requirements and those with demanding requirements. Through these two proposed processes, BIM designers should be able to determine the proper solution for any pursuit project that they encounter.

Finaly, this chapter concluded with the detailed overview of the scope, baseline information, and required deliverables of the two proposed case studies. These case studies aim to provide conclusive quantitative and qualitative evidence of the proposed workflow’s efficacy.

CHAPTER 4: RESULTS

This chapter represents the culmination of the results of research presented in this work thus far and provides in-depth results from each of the conducted case studies. The aim of this section is to provide the results of each of the complete case studies in an easily digestible manner in order to further answer the research questions posed at the beginning of the previous chapter. The data presented in this chapter will aid in determining the feasibility of the proposed "best practice" workflow in creating visualization deliverables for pursuit projects of varying levels of commitment. The research findings section will present key findings of the case studies and is organized into three main topics based on the 'best practice" process utilized to develop the associated visualization deliverable package. This section will outline the results of each case study, while also providing objective analysis of each key performance indicator (KPI) of project success. As this is a results chapter, any subjective interpretations of this data will be reserved for the subsequent discussion chapter.

The results in this section are presented through a mixture of both numerical and visual formats. These formats come in the form of data tables and figures to enhance the clarity of the results, while also supporting rapid interpretation of the final data. For further context, the deliverable packages developed for each circumstance are provided in appendices B, C, D, E.

This chapter will conclude with a section that summarizes the final conclusions of the research questions posed based on the data provided in this section. This section will take a data driven approach to answering these research questions in an objective manner. As previously stated in regard to the research findings sections, all subjective interpretations of the answers provided in the research conclusion section will be reserved for the subsequent discussion chapter.

4.1 RESEARCH FINDINGS

As mentioned previously, this section's main focus will be on providing objective results through both numerical and visual data. In order to best organize this data, the findings have been separated by case study and the required demand of the associated project. The subsequent three sections will provide a breakdown of each process in regard to all project tasks associated with developing the required visualization of deliverable packages. These breakdowns will also include brief objective analysis of the results and comparison to baseline data obtained through traditional development of these deliverable packages. For the sake of organization, the deliverable packages developed in each section will be provided in an associated appendix.

Findings of Case Study 1: PBC WTP 2

The case study of the Palm Beach County Water Treatment Plant 2 pursuit project was aimed at providing a definitive comparison of the proposed "best practice" workflow and the traditional workflow used to develop visualization deliverable packages for pursuit projects. The data presented in this section was collected over the course of the development of the desired visualization deliverables and, in regard to the existing workflow, was obtained through detailed notes kept during the initial process. The findings presented in this section will provide both quantitative and qualitative evidence that suggests that the proposed "best practice" workflow outperforms the traditional workflow. Deliverable packages developed for PBC WTP 2 utilizing both the traditional and proposed workflows are included in appendices B and C, respectively.

Topographic Surface Creation

In regard to topographic surface creation, the google earth process required by the traditional workflow, in total, took approximately 15.37 hours to complete. In the case of the proposed "best practice method, it took around 5.63 hours to generate a topographic surface of the same quality utilizing the CAD Mapper method. A detailed breakdown of each task that contributes to these total completion times is provided below:

Table 4.1.1: PBC WTP 2 Time Req. for Generating Topo Surface with Traditional Workflow

Step	Google Earth Method (Traditional Workflow)	PBC Completion Time (Hrs)
1	Screenshot Google Earth Image	0.05
2	Insert Image into Revit and Scale	0.017
3	Create Topo Solid from Sketch	0.05
4	Use elevations from Google Earth to Build out Topo Solid	10
6	Add Features	5.25
	Total	15.37

Table 4.1.2: PBC WTP 2 Time Req. for Generating Topo Surface with Proposed Workflow

Step	CAD Mapper Method ("Best Practice" Workflow)	PBC Completion Time (Hrs)
1	Source DXF from CAD Mapper	0.08
2	Import DXF to Revit	0.02
3	Convert DXF File to Topo Solid	0.03
4	Clean	0.25
5	Add Features (Same Process as Traditional)	5.25
	Total	5.63

Based on these times, it can be determined that the proposed "best practice" workflow for generating topographic surfaces saved approximately 9.74 hours or $413.17 (based on a labor burden rate of $42.42/hr). While the quality is similar for both surfaces, the topographic surfaces generated are provided on the next page for quality assessment purposes:

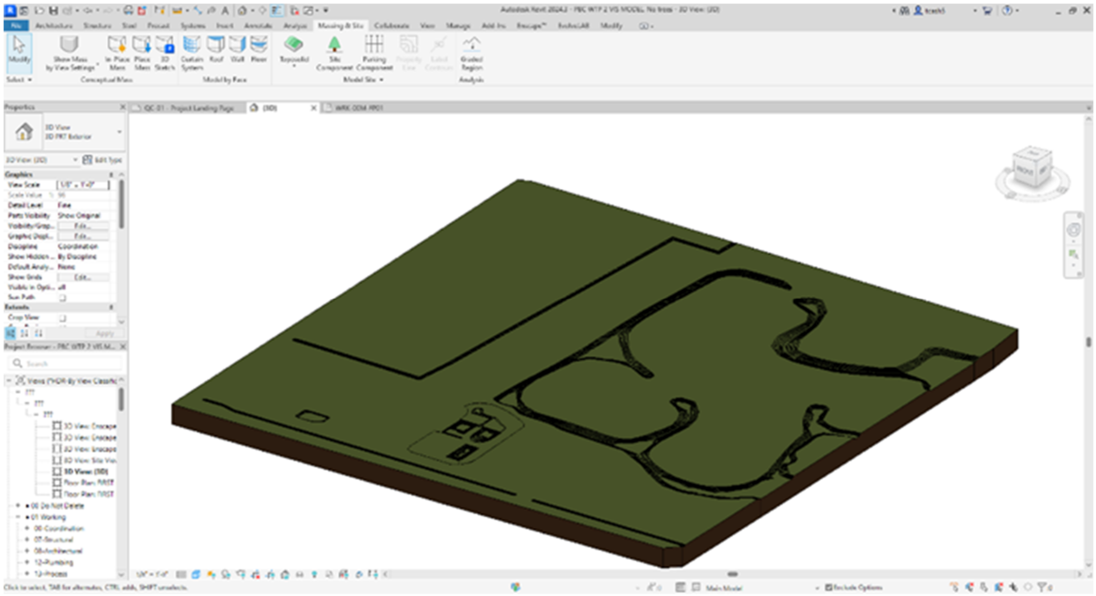

Figure 4.1.74: PBC WTP Topographic Surface Generated Using Traditional Workflow

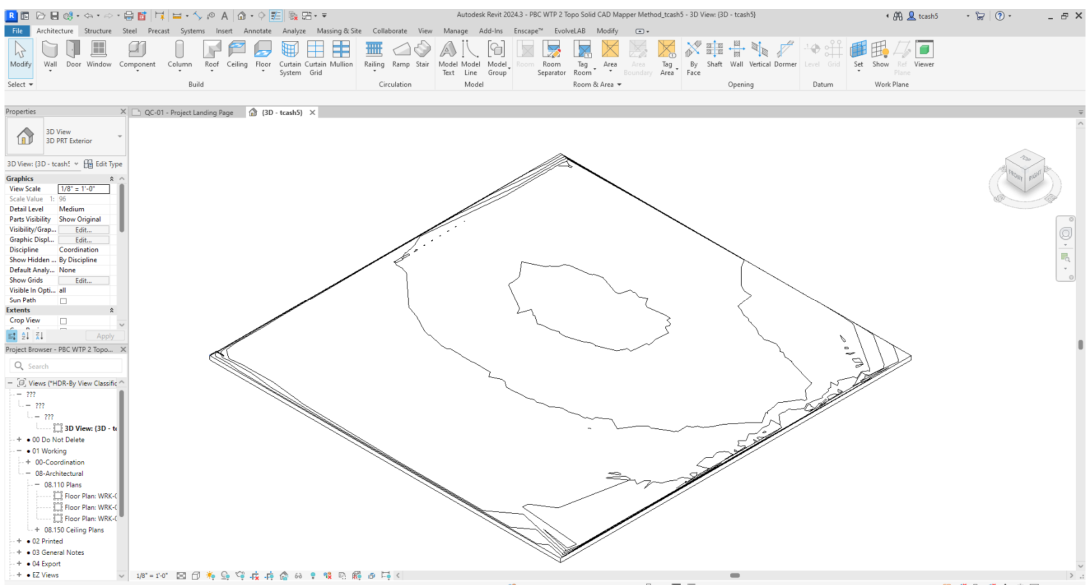

Figure 4.1.75: PBC WTP 2 Topographic Surface Generated Using "Best Practice" Workflow

Existing & Proposed Equipment Modeling

For existing and proposed equipment modeling, the generic modeling method utilized in the traditional workflow took approximately 5.70 hours for all necessary equipment families to be developed and placed. With the parametric model library method utilized by the "best practice" workflow, this same process took approximately 1.30 hours. A detailed breakdown of each time requirement is provided in the subsequent tables on the next page:

Table 4.1.3: PBC WTP 2 Time Req. for Traditional & Proposed Methods for Family Creation

PBC WTP 2 Time Requirements Utilizing Traditional & Proposed Methods for Family Creation					
Family	**Number of Instances**	**Generic Family Model Time (Mins.)**	**Parametric Family Model Time (Mins.)**	**Dynamo Scripting Time (Mins.)**	**Time Required for Placement (Assuming 1 Min/Instance)**
Degassifiers	6	20	30	30	6
Odor Control Scrubbers	8	60	160	30	8
Poly Storage Tank/Chem Storage Tank	5	15	35	30	5
Ground Storage Tank	4	10	25	30	4
Fuel Storage Tanks	2	10	35	30	2
Flat Top Storage Tank (No Manway)	5	2	5	30	5
Flat Top Storage Tank (With Manway)	1	5	15	30	1
Chemical Containment Tank (No Manway)	21	5	15	30	21
Cartridge Filters	6	45	60	30	6
Vertical Turbine Pump	15	60	120	50	15
Generator	4	30	45	30	4
Control Panel	1	2	5	30	1
Total Minutes		264	550	380	78
Total Hours		4.40	9.17	6.33	1.30

Table 4.1.4: PBC WTP 2 Key Statistics for Family Creation of Existing and Proposed Equipment

PBC WTP 2 Key Time Statistics (In Hours)	
Parametric Method Prep Time *(Not Considered)*	15.50
Traditional Method Time Requirement *(Generic Modeling & Placement)*	5.70
Parametric Method Time Requirement *(Placement Only)*	1.30
Total Time Saved by Using Proposed Method	4.40

Based on these times, it can be determined that the proposed “best practice” workflow for equipment family creation saved approximately 4.40 hours or $186.65 (based on a labor burden rate of $42.42/hr). While the quality is similar for both family types, the parametric families developed for the created library have a slightly reduced level of detail. The images below are provided for quality assessment purposes:

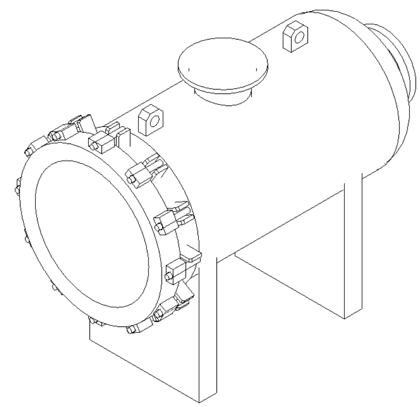

Figure 4.1.76: PBC WTP 2 Generically Modeled Cartridge Filter for Traditional Workflow

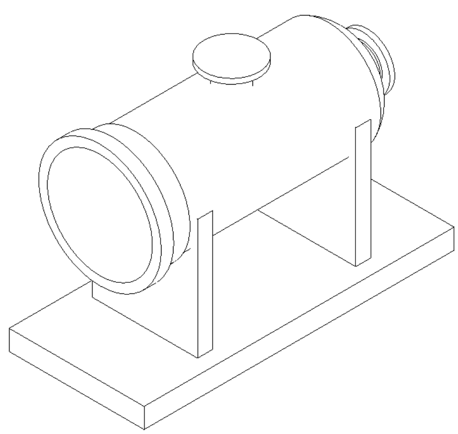

Figure 4.1.77: PBC WTP 2 Parametrically Modeled Cartridge Filter for "Best Practice" Workflow

Development of a High LOD Revit Model

The process of developing high LOD Revit models is common amongst both the traditional and proposed workflows. For PBC WTP 2, this process took approximately 91.70 hours and cost about $3889.91 to complete (based on a labor burden rate of $42.42). This process consists of developing a model containing all existing and proposed elements required for the project through traditional modeling methods. While this is the most time-consuming portion of the development of visualization deliverables, it is unlikely that these time requirements can be reduced without severely impacting the final quality of the model. A detailed breakdown of these modeling times is provided below to aid in analysis:

Table 4.1.5: PBC WTP 2 Revit Model Development Times Based on HLOD Requirements

PBC WTP 2 High LOD Model Development Time Requirement	
Task	**Time Required (Hrs.)**
Proposed Structure Revit Modeling	10.0
Existing Element Revit Modeling	81.70
Total	91.70

Developing Visualization Models

The process for developing visualization models from BIM models is common amongst both the traditional and proposed workflows. These workflows utilize Twinmotion to create visually stunning visualization models from imported Revit models. For PBC WTP 2, this process took approximately 3 hours and cost around $127.26 to complete (based on a labor burden rate of $42.42). This process consists of importing Revit models into Twinmotion, adding trees, and applying materials to modeled elements. A detailed breakdown of these time requirements is provided below to aid in analysis:

Table 4.1.6: PBC WTP 2 Visualization Model Development Time Requirements by Process

PBC WTP 2 Visualization Model Development Time Requirements	
Visualization Process	**Twinmotion Time Requirement (Hrs.)**
Modeling Trees	1.00
Applying Materials	2.00
Total	3.00

Creating Rendered Still Images

The process for creating still image renderings from visualization models is common amongst both the traditional and proposed workflows. These workflows utilize Twinmotion tools in order to rapidly create rendered images of desired locations within the visualization model.

For PBC WTP 2, this process took approximately 0.58 hours and cost around $24.60 to produce (based on a labor burden rate of $24.24/hr). This process consists of carefully creating desired images within Twinmotion and exporting all of the created images to the desired storage location on the user's hard drive. As this process only consists of a single task and its total time commitment is under one hour, a table is not necessary to aid in further analysis. For effective examples of still images developed for each workflow, please see appendices B and C, respectively.

Creating Rendered Section Cuts

Originally, rendered section cuts were not part of the deliverable package developed through the traditional workflow. These images are associated with the supplemental work package that is offered due to the time savings produced by the proposed "best practice" workflow. For PBC WTP 2, these images were developed in approximately 0.33 hours and cost around $13.99 to produce (based on a labor burden rate of $42.42/hr). This process consists of defining a section box within the Revit model space and then utilizing Enscape to render the desired section image. As this process only consists of a single task and its total time commitment under one hour, a table is not necessary to aid in further analysis. For effective examples of section images developed utilizing the proposed workflow, please see appendix C.

Creating Rendered Videos

The process for creating video renderings from visualization models is common amongst both the traditional and proposed workflows. These workflows utilize Twinmotion tools to rapidly create desired video clips based on user defined keyframes. For PBC WTP 2, this process took approximately 0.67 hours and cost $28.42 to produce (based on a labor burden rate of $42.42/hr). This process consists of defining keyframes within Twinmotion's video creator to develop desired video clips and then batch exporting these clips to the desired location on the user's hard drive. As this process only consists of a single task and its total time commitment under one hour, a table is not necessary to aid in further analysis. For effective examples of rendered videos developed for each workflow, please see appendices B and C.

Exporting an Executable Project Presentation

Originally, providing an executable project presentation was not part of the deliverable package developed through the traditional workflow. This executable file is associated with the supplemental work package that is offered due to the time savings produced by the proposed "best practice" workflow. For PBC WTP 2, the executable presentation file was developed in approximately 0.33 hours and cost around $13.99 to produce (based on a labor burden rate of $42.42/hr). This process consists of exporting an Enscape model of the desired BIM model through utilization of Enscape's "Export to EXE…" function. As this process only consists of a single task and its total time commitment under one hour, a table is not necessary to aid in further analysis. For effective examples of the exportable executable file developed for the proposed workflow, please see appendix C.

Generating a VR Environment

Originally, providing a VR environment was not part of the deliverable package developed through the traditional workflow. The VR environment is associated with the supplemental work package that is offered due to the time savings produced by the proposed "best practice" workflow. For PBC WTP 2, the VR environment was developed in approximately 0.08 hours and cost around $3.39 to produce (based on a labor burden rate of $42.42/hr). This process consists of configuring the VR environment within the Enscape executable file's settings and launching the VR viewer within the application. As this process only consists of a single task and its total time commitment under one hour, a table is not necessary to aid in further analysis. For effective examples of the VR environment developed for the proposed workflow, please see appendix C.

Supplemental Image & Video Generation Utilizing AI

Originally, providing supplemental images and videos was not part of the deliverable package developed through the traditional workflow. The supplemental AI generations are associated with the supplemental work package that is offered due to the time savings produced by the proposed “best practice” workflow. For PBC WTP 2, the supplemental AI generations took approximately 1 hour to produce and cost around $42.42 (based on a labor burden rate of $42.42/hr). This process consists of utilizing a combination EvolveLAB’s Veras and Runway ML to develop stunning AI generations from the model. As this process only consists of a total time commitment of one hour, a table is not necessary to aid in further analysis. Keep in mind that each AI generation took approximately 10 minutes to complete (6 generations). For effective examples of these supplemental AI generations developed for the proposed workflow, please see both the AI images and AI videos highlighted in appendix C.

Summary of Results

This section has provided an in-depth overview of the results of the Palm Beach County Water Treatment Plant 2 pursuit project. These results should provide enough information to determine the efficacy of the proposed “best practice” workflow by comparison to the traditional workflow. Based on the data collected throughout the case study, the following tables have been provided to summarize the results for both the traditional and proposed “best practice” workflows:

Table 4.1.7: PBC WTP 2 Summary of Results for Traditional Workflow

PBC WTP 2 Summary of Results for Traditional Workflow			
Step	**Task**	**Time Requirement (Hrs.)**	**Cost ($)**
1	Topographic Surface Creation	15.37	$ 652.00
2	Existing/Proposed Equipment Modeling	5.7	$ 241.79
3	Development of Proposed Structures in Revit	10	$ 424.20
4	Miscellaneous Revit Modeling Tasks	81.7	$ 3,465.71
5	Developing Visualization Models	3	$ 127.26
6	Creating Rendered Still Images	0.58	$ 24.60
8	Rendered Videos	0.67	$ 28.42
	Totals	**117.02**	**$ 4,963.99**

Table 4.1.8: PBC WTP 2 Summary of Results for "Best Practice" Workflow

PBC WTP 2 Summary of Results for "Best Practice" Workflow			
Step	**Task**	**Time Requirement (Hrs.)**	**Cost ($)**
1	Topographic Surface Creation	5.63	$ 238.82
2	Existing/Proposed Equipment Modeling	1.3	$ 55.15
3	Development of Proposed Structures in Revit	10	$ 424.20
4	Miscellaneous Revit Modeling Tasks	81.7	$ 3,465.71
5	Developing Visualization Models	3	$ 127.26
6	Creating Rendered Still Images	0.58	$ 24.60
7	Rendered Videos	0.67	$ 28.42
	Required Totals	**102.88**	**$ 4,364.17**
8	Rendered Section Cuts	0.33	$ 14.00
9	Executable Project Files **If required**	0.33	$ 14.00
10	VR Environments **If required**	0.08	$ 3.39
11	Live Model Demonstrations/Walkthroughs **If required**	0	$ -
12	Supplemental Image/Video Generation **If required**	1	$ 42.42
	Supplemental Totals	**1.74**	**$ 73.81**
	Totals	**104.62**	**$ 4,437.98**

Based on the information provided in these tables, it can be determined that the proposed "best practice" workflow reduced the time commitment for producing the required deliverables by approximately 14.14 hours. This reduction in time commitment reflects a cost savings of approximately $599.82 (based on a labor burden rate of $42.42/hr). This reduced time commitment also created the potential for the production of supplementary deliverables to further aid the design team's ability to convey their proposed design and offer increased quality to the deliverable package. These supplementary deliverables only require an additional time commitment of 1.74 hours and an additional cost of $73.81, which still reflects total time savings of approximately 12.4 hours and total cost savings of $526.01.

Findings of Case Study 2: Concord Hillgrove GAC Upgrade Utilizing Average Requirements

The case study of the Concord Hillgrove Granular Activated Carbon Upgrade pursuit project was aimed at providing conclusive evidence that the proposed "best practice" workflow could be effectively applied to projects of varying scope. The data presented in this section was collected over the course of the development of the desired visualization deliverables. The findings presented in this section will provide both quantitative and qualitative evidence that suggests that the proposed "best practice" workflow can be universally applied to any project pursuit. While the traditional workflow was not utilized for this case study, a general estimate of the hours required was produced through previous experience and coordination with the project's pursuit team. Overall, it was determined that utilizing the traditional workflow to produce the desired deliverables would take approximately 80 hours and cost around $3393.60 (based on a labor burden rate of $42.42/hr). This general estimate will be used to provide a baseline comparison of the traditional and "best practice" workflows. The visualization deliverable package prepared in this section assumes both average time constraints and monetary budget. The deliverable package developed for the Concord Hillgrove GAC Upgrade pursuit utilizing the "best practice" process for average projects is included in appendix D.

Topographic Surface Creation

In regard to topographic surface creation, this case study utilized the "best practice" CAD Mapper method. Based on the data collected during this process, a detailed breakdown of the time required to complete each task is provided by the table below:

Table 4.1.9: Concord Hillgrove Time Req. for Generating Topo Surface with Proposed Workflow

Step	CAD Mapper Method	Concord Hillgrove Completion Time (Hrs.)
1	Source DXF from CAD Mapper	0.08
2	Import DXF to Revit	0.02
3	Convert DXF File to Topo Solid	0.03
4	Clean	0.50
5	Add Features	5.25
	Total	5.88

Based on these times, it can be determined that the proposed "best practice" workflow for generating topographic surfaces took approximately 5.88 hours and cost around $249.43 (based on a labor burden rate of $42.42/hr). An image of the created topographic surface for this process is provided below for quality assessment purposes:

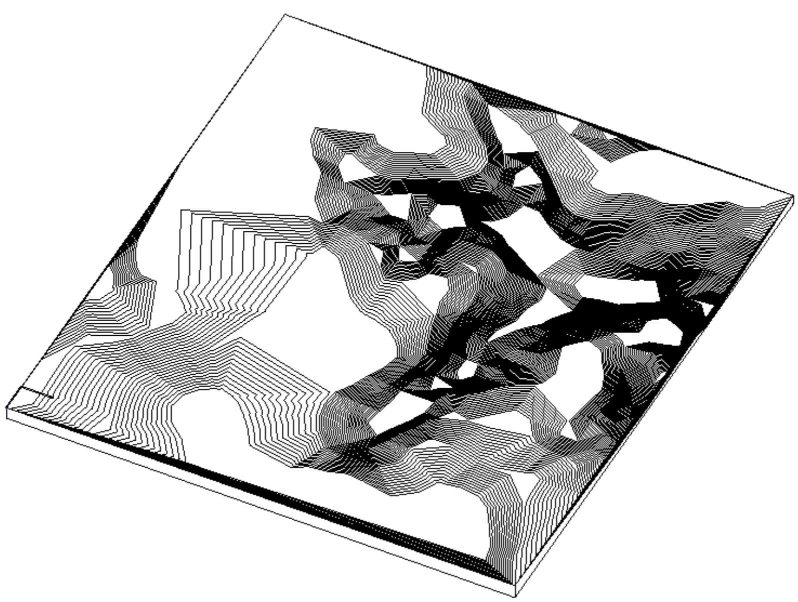

Figure 4.1.78: Concord Hillgrove Topographic Surface for "Best Practice" Process with Avg. Req.

Existing & Proposed Equipment Modeling

In regard to existing and proposed equipment modeling, this case study utilized the “best practice” parametric library method. Based on the data collected during this process, a detailed breakdown of the time required to complete each task is provided by the tables below:

Table 4.1.10: Concord Hillgrove Time Req. for Family Creation with Proposed Workflow

Concord Hillgrove Time Requirements Utilizing Proposed Methods for Family Creation				
Family	**Number of Instances**	**Parametric Family Model Time (Mins.)**	**Dynamo Scripting Time (Mins.)**	**Time Required for Placement (Assuming 1 Min/Instance)**
GAC Contactor Tank	4	150	45	4
Water Tower	1	50	30	1
Total Minutes		**200**	**75**	**5**
Total Hours		**3.33**	**1.25**	**0.08**

Table 4.1.11: Concord Hillgrove Key Statistics for Family Creation with Proposed Workflow

Concord Hillgrove Key Time Statistics (In Hours)	
Parametric Method Prep Time *(Not Considered)*	4.58
Parametric Method Time Requirement *(Placement Only)*	0.08

Based on these times, it can be determined that the proposed “best practice” workflow for existing and proposed equipment modeling takes approximately 0.08 hours and costs around $3.39 (based on a labor burden rate of $42.42/hr). An example of the created parametric equipment families utilized in this process is provided below for quality assessment purposes:

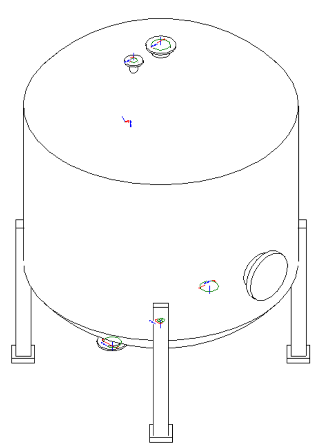

Figure 4.1.79: Concord Hillgrove Parametric Family Created for Proposed Workflow

Development of a High LOD Revit Model

Based on the requirements of the project, it was necessary to develop the Revit model to an elevated level of detail. For Concord Hillgrove, this process took approximately 39.56 hours and cost around $1678.14 (based on a labor burden rate of $42.42/hr). This process consists of developing a model containing all existing and proposed elements required for the project through traditional modeling methods. Although this process is time consuming, it is deemed necessary to ensure the final quality of the deliverable package. A detailed breakdown of these modeling times is provided below to aid in analysis:

Table 4.1.12: Concord Hillgrove HLOD Modeling Times for Proposed Workflow

Concord Hillgrove High LOD Model Development Time Requirement	
Task	**Time Required (Hrs.)**
Proposed Structure Revit Modeling	4
Existing Element Revit Modeling	35.56
Total	39.56

Developing Visualization Models

The proposed "best practice" workflow for projects with average requirements utilizes Twinmotion to create a visually stunning visualization model from an imported Revit model. For Concord Hillgrove, this process took approximately 1.58 hours and cost around $67.17 to complete (based on a labor burden rate of $42.42). This process consists of importing the Revit model into Twinmotion, adding trees, and applying materials to modeled elements. A detailed breakdown of these time requirements is provided below to aid in analysis:

Table 4.1.13: Concord Hillgrove Visualization Model Development Time Requirements by Task

Concord Hillgrove Visualization Model Development Time Requirements	
Visualization Process	**Twinmotion Time Requirement (Hrs.)**
Modeling Trees	0.67
Applying Materials	0.92
Total	1.58

Creating Rendered Still Images

Regarding the creation of rendered still images for projects with average requirements, the "best practice" workflow utilizes Twinmotion tools in order to rapidly create rendered images of desired locations within the visualization model. For Concord Hillgrove, this process took approximately 0.5 hours and cost around $21.21 to produce (based on a labor burden rate of $24.24/hr). This process consists of carefully creating desired images within Twinmotion and exporting all of the created images to the desired storage location on the user's hard drive. As this process only consists of a single task and its total time commitment is under one hour, a table is not necessary to aid in further analysis. For effective examples of still images developed for the proposed workflow, please see appendix D.

Creating Rendered Section Cuts

Regarding the creation of rendered section cuts for projects with average requirements, the "best practice" workflow utilizes Enscape tool in order to rapidly create rendered section cuts within the visualization model. For Concord Hillgrove, these images were developed in approximately 0.17 hours and cost around $7.21 to produce (based on a labor burden rate of $42.42/hr). This process consists of defining a section box within the Revit model space and then utilizing Enscape to render the desired section image. As this process only consists of a single task and its total time commitment under one hour, a table is not necessary to aid in further analysis. For effective examples of section images developed utilizing the proposed workflow, please see appendix D.

Creating Rendered Videos

Regarding the creation of rendered videos for projects with average requirements, the "best practice" workflow utilizes Twinmotion tools to rapidly create desired video clips based on user defined keyframes. For Concord Hillgrove, this process took approximately 0.58 hours and cost $24.75 to produce (based on a labor burden rate of $42.42/hr). This process consists of defining keyframes within Twinmotion's video creator to develop desired video clips and then batch exporting these clips to the desired location on the user's hard drive. As this process only consists of a single task and its total time commitment under one hour, a table is not necessary to aid in further analysis. For effective examples of rendered videos developed utilizing the proposed workflow, please see appendix D.

Exporting an Executable Project Presentation

Regarding the creation of an exportable project presentation file for projects with average requirements, the "best practice" workflow utilizes Enscape to complete this process. For Concord Hillgrove, the executable presentation file was developed in approximately 0.33 hours and cost around $13.99 to produce (based on a labor burden rate of $42.42/hr). This process consists of exporting an Enscape model of the desired BIM model through utilization of Enscape's "Export to EXE…" function. As this process only consists of a single task and its total time commitment under one hour, a table is not necessary to aid in further analysis. For an effective example of the exportable executable file developed for the proposed workflow, please see appendix D.

Generating a VR Environment

Regarding the creation of a VR environment for projects with average requirements, the "best' practice workflow utilizes Enscape to complete this process. For Concord Hillgrove, the VR environment was developed in approximately 0.08 hours and cost around $3.39 to produce (based on a labor burden rate of $42.42/hr). This process consists of configuring the VR environment within the Enscape executable file's settings and launching the VR viewer within the application. As this process only consists of a single task and its total time commitment under one hour, a table is not necessary to aid in further analysis. For an effective example of the VR environment developed for the proposed workflow, please see appendix D.

Supplemental Image & Video Generation Utilizing AI

Regarding supplemental AI generations for projects with average requirements, the "best practice" workflow produces generations from Revit models developed to a HLOD. For Concord Hillgrove, the supplemental AI generations took approximately 0.33 hours to produce and cost around $13.99 (based on a labor burden rate of $42.42/hr). This process consists of utilizing a combination EvolveLAB's Veras and Runway ML to develop stunning AI generations from the model. As this process only consists of a total time commitment of one hour, a table is not necessary to aid in further analysis. Keep in mind that each AI generation took approximately 10 minutes to complete (2 generations). For effective examples of these supplemental AI generations developed for the proposed workflow, please see both the AI images and AI videos highlighted in appendix D.

Summary of Results

This section has provided an in-depth overview of the results of the Concord Hillgrove GAC Upgrade pursuit project assuming average requirements. These results should provide enough information to determine the efficacy of the proposed "best practice" workflow on unseen projects of varying scope. Based on the data collected throughout the case study, the following table has been provided to summarize the results for the proposed "best practice" workflow:

Table 4.1.14: Concord Hillgrove Summary of Results for Proposed Workflow with Avg. Req.

Concord Hillgrove Summary of Results for "Best Practice" Workflow with Avg. Req.			
Step	**Task**	**Time Requirement (Hrs.)**	**Cost ($)**
1	Topographic Surface Creation	5.88	$ 249.43
2	Existing/Proposed Equipment Modeling	0.08	$ 3.39
3	Development of Proposed Structures in Revit	4	$ 169.68
4	Miscellaneous Revit Modeling Tasks	35.56	$ 1,508.46
5	Developing Visualization Models	1.58	$ 67.02
6	Rendered Still Images	0.5	$ 21.21
7	Rendered Videos	0.58	$ 24.60
8	Rendered Section Cuts	0.17	$ 7.21
9	Executable Project File	0.33	$ 14.00
10	VR Environment	0.08	$ 3.39
11	Live Model Demonstrations/Walkthrough	0	$ -
12	Supplemental Image/Video Generation	0.33	$ 14.00
	Totals	**49.09**	**$ 2,082.40**

Based on the information provided in the table, it can be determined that, when compared to the initial estimate of 80 hours, the proposed "best practice" workflow reduced the time commitment for producing the required deliverables by approximately 30.91 hours. This reduction in time commitment reflects a cost savings of approximately $1311.20 (based on a labor burden rate of $42.42/hr). This reduced time requirement mitigates the risk of losing the project pursuit and allows the BIM designer to work at maximum efficiency towards the creation of the desired visualization deliverables.

Findings of Case Study 2: Concord Hillgrove GAC Upgrade Utilizing Demanding Requirements

In the hypothetical situation that the Concord Hillgrove GAC Upgrade project pursuit must be completed with demanding requirements, the project would need to be completed on an expedited timeline. Through utilization of the proposed "best practice" process for projects with demanding requirements, AI tools will be utilized in order to create the simplest form of visualization deliverables: still images and videos. Through focusing on only two deliverable types, this allows BIM designers to focus heavily on the final quality without inflating the time required to develop the deliverable package. The goal of this part of case study 2 is to provide conclusive evidence that, through utilization of AI, the "best practice" workflow will make completion of these high demand projects plausible, while preserving a desired level of quality. For the deliverable package developed for the Concord Hillgrove GAC Upgrade pursuit utilizing the "best practice" process for demanding projects, please see appendix E.

Topographic Surface Creation

For pursuit projects with demanding requirements, the process of topographic surface creation is the same as that of projects with average requirements. The innate speed and quality of the CAD mapper method makes it effective in both average and demanding situations. Therefore, the same statistics from the previous Concord Hillgrove section can be utilized. In summary, the creation of a topographic surface through utilization of the "best practice" method takes approximately 5.88 hours and cost around $249.43 (based on a labor burden rate of $42.42/hr).

Existing & Proposed Equipment Modeling

For pursuit projects with demanding requirements, the process of equipment family creation is the same as that of projects with average requirements. The efficiency of the parametric library method makes it effective in both average and demanding situations. Therefore, the same statistics from the previous Concord Hillgrove section can be utilized. In summary, the creation of equipment models through utilization of the "best practice" method takes approximately 0.08 hours and costs around $3.39 (based on a labor burden rate of $42.42/hr).

Development of a Low LOD Revit Model

Based on the demanding requirements in this scenario, it was only necessary to develop the Revit model to a low level of detail. This is because AI models will be used to infer any details that need to be generated. Therefore, for Concord Hillgrove, this process took approximately 8 hours and cost around $339.36 (based on a labor burden rate of $42.42/hr). This process consists of developing a model containing all existing elements and then quickly modeling simple geometry to represent the proposed elements required for the project. A detailed breakdown of these modeling times is provided below to aid in analysis:

Table 4.1.15: Concord Hillgrove LLOD Modeling Times for Proposed Workflow

Concord Hillgrove Low LOD Model Development Time Requirement	
Task	**Time Required (Hrs.)**
Proposed Structure Revit Modeling	0.5
Existing Element Revit Modeling	7.5
Total	8

Generating AI Visualization Deliverables

Regarding the production of AI visualization deliverables for projects with demanding requirements, the "best practice" workflow produces generations from Revit models developed to a LLOD. For Concord Hillgrove, the AI generations took approximately 1.25 hours to produce and cost around $53.03 (based on a labor burden rate of $42.42/hr). This process consists of utilizing a combination EvolveLAB's Veras and Runway ML to develop stunning AI generations from the model without the need for high LOD. In order to provide a detailed breakdown of these time requirements, a table is provided below:

Table 4.1.16: Concord Hillgrove LLOD AI Generation Times for Proposed Workflow

Concord Hillgrove Low LOD AI Generation Time Requirement	
Task	**Time Required (Hrs.)**
AI Generated Images	1
AI Generated Videos	0.25
Total	1.25

For effective examples of both AI generated images and videos, please see the deliverable package developed for the Concord Hillgrove project with demanding requirements located in appendix E.

Summary of Results

This section has provided an in-depth overview of the results of the Concord Hillgrove GAC Upgrade pursuit project assuming demanding requirements. These results should provide enough information to determine the efficacy of the proposed "best practice" workflow on projects with either demanding time requirements or budgetary constraints. Based on the data collected throughout the case study, the following table has been provided to summarize the results for the proposed "best practice" workflow:

Table 4.1.17: Concord Hillgrove Summary of Results for Proposed Workflow with Demanding Req.

Concord Hillgrove Summary of Results for "Best Practice" Workflow with Demanding Req.			
Step	**Task**	**Time Requirement (Hrs.)**	**Cost ($)**
1	Topographic Surface Creation	5.88	$ 249.43
2	Existing/Proposed Equipment Modeling	0.08	$ 3.39
3	Development of Proposed Structures in Revit	0.5	$ 21.21
4	Miscellaneous Revit Modeling Tasks	7.5	$ 318.15
5	AI Image Generation	1	$ 42.42
6	AI Video Generation	0.25	$ 10.61
	Totals	**15.21**	**$ 645.21**

Based on the information provided in the table, it can be determined that, when compared to the results of the "best practice" process for projects with average requirements, the proposed "best practice" process for projects with demanding requirements reduced the time commitment for producing the required deliverables by approximately 33.88 hours. This reduction in time commitment reflects cost savings of approximately $1437.19 (based on a labor burden rate of $42.42/hr). When compared to the estimate developed using the traditional workflow, this process reduces the overall time requirement by approximately 64.79 hours and the cost of producing the deliverable package by $2,748.39. This reduced time and cost allows BIM designers to apply effective solutions to projects with demanding requirements, albeit at a slight reduction to the final quality of the deliverable package.

4.2 RESEARCH CONCLUSIONS

Throughout the duration of this study, multiple research questions were posed in regard to improving key processes, selecting beneficial tools to complete key tasks, and utilizing innovative technologies to improve existing workflows. This section will aim to provide objective answers to these research questions through interpretation of the findings resulting from the two case studies: The PBC WTP 2 and Concord Hillgrove GAC Upgrade pursuit projects. As stated in the introduction to this chapter, this section will take a data driven approach in order to answer these questions in the most objective terms possible. All subjective interpretations will be reserved for the subsequent discussion chapter. The answers provided in this section will be split into subsections that are categorized by the individual questions that were posed throughout this study.

What is the most effective method for topographic surface creation?

Through the results of both case studies and the preceding research, it can be determined that the CAD Mapper method is definitively the most effective method for topographic surface creation. When compared to the traditional google earth method, the CAD Mapper method, on average, is 3.48 times faster at producing topographic surfaces of a high quality. When compared to the LiDAR method examined in this research, the CAD Mapper method, on average, is 1.83 times faster at producing topographic surfaces. It can also be determined that an average topographic surface developed utilizing the CAD Mapper method costs approximately 45.24% less than those developed with the LiDAR method and 71.27% less than those developed with the traditional Google Earth method. While the topographic surface developed utilizing the LiDAR method is generally more accurate, for pursuit project this level of accuracy is not always required and does not justify the increased time requirement. These statistics alone are why the CAD Mapper method is definitively the most effective method for topographic surface creation.

Is it beneficial to develop parametric families and dynamo scripts for the purpose of creating visualization models?

Based on the data collected through both case studies and the preceding research, it can be concluded that the development of a parametric library of families and associated dynamo scripts provides significant benefits to the creation of visualization models. Every pursuit for a water or wastewater project requires that multiple instances of equipment be created within the Revit model. When compared to the existing generic modeling method, the parametric library method, on average, is approximately 42 times faster per instance of required equipment created within a given model. It can also be determined that the average cost per instance of equipment associated with the parametric library method is 97.61% less than that of instances created with the generic modeling method. The results are so starkly different because it is assumed that the library of parametric families has already been created at the onset of the project, thus no family creation would be required and only placement time would be considered. Therefore, based on these statistics it can be determined that the development of this library of parametric families and associated dynamo scripts has substantial benefit to the creation of visualization models for pursuit projects.

Does AI create opportunities to reduce the required time commitment of creating image and video visualizations of proposed structures?

Based on the results of case study 2, which was conducted utilizing both the “best practice” processes for projects with average and demanding requirements, respectively, it can be concluded that AI diffusion models create opportunities for the reduction of the time required to produce both image and video visualizations for deliverable packages. These AI models provide this opportunity by reducing the overall level of detail that is required from the Revit model. Through the production of a low LOD Revit model, these diffusion models reduce the overall time required by 69.01% when compared to the time required of higher LOD models. It can also be determined that, when utilizing the AI models to develop the visualization deliverables, the overall cost is reduced by a factor of 3.23. These benefits come with a slight caveat that, through the reduction of detail, the results will be more sporadic and a smaller number of final deliverables will be provided. Therefore, this caveat must be accepted by pursuit team in order to seize the opportunities that these models provide.

Enscape vs. Twinmotion: What are the specific use cases for each rapid visualization program?

Through the research conducted throughout this study, it can be concluded that the "best practice" use cases for both Twinmotion and Enscape are as follows:

Table 4.1.18: Summary of "Best Practice" Visualization Software Selections by Task

Summary of "Best Practice" Visualization Software Selections by Task	
Task	**Software Selection**
Developing Visualization Models	Twinmotion
Creating Rendered Still Images	Twinmotion
Rendered Section Cuts	Enscape
Rendered Videos	Twinmotion
Executable Project Files	Twinmotion/Enscape
VR Environments	Enscape
Live Model Demonstrations/Walkthroughs	Enscape

These "best practice" software selections were made by determining the areas in which each visualization software preformed at peak efficiency. Through extensive experimentation, it was determined that Enscape performed better in live processes that are prone to performance issues, while Twinmotion performed better on production tasks that required a higher level of detail. The one process in which this was not the case was the creation of rendered images of section cuts. In this case, Enscape was selected over Twinmotion because it utilizes Revit's excellent section tool, while Twinmotion utilizes a tool within its toolbox that feels tedious to use at times.

Are Autodesk Workshop XR and Resolve BIM viable options for creating interactive project walkthroughs for pursuit interviews?

While Autodesk Workshop XR and Resolve BIM offer impressive VR capabilities for internal model review, it can be concluded that, at the current time, these applications would be too difficult to implement on a large scale for pursuit interviews. The reasons cited for this are the requirement that all pursuit interview attendees have access to a compatible VR headset, VR hesitancy amongst the working population, and the lack of visual aesthetic of the models within the current applications. However, as these reasons are alleviated by the improvement of VR technology and increased availability of VR headsets, applications like these have potential to revolutionize how pursuit interviews are conducted. For this reason, it can also be concluded that, although this emerging technology cannot currently carry a pursuit interview, it could have an immense impact on pursuit interviews in the near future.

Does the proposed "best practice" workflow provide benefit to project pursuits with average time requirements and monetary constraints?

According to the data collected for both case studies, it can be determined that the proposed "best practice" workflow does provide significant benefit to any given pursuit project with average requirements. Through the utilization of the "best practice" process for projects with average requirements on both case studies, a total of $1,837.21 and 41.31 hours were saved, when compared to the results of the traditional workflow. This means that the proposed workflow reduced the total completion time of these two projects by an entire work week (40 hours) and reduced the monetary risk of losing the pursuit project by $1,837.21. These benefits were also achieved despite increasing the number of desired deliverables and including a supplemental deliverable package. Therefore, there is an additional benefit from an overall increase in the quality of the final deliverable package.

Does the proposed "best practice" workflow provide benefit to project pursuits with demanding time requirements and monetary constraints?

According to the data collected for the Concord Hillgrove case study, it can be concluded that the proposed "best practice" workflow provides significant benefits to any given pursuit project with demanding requirements. This workflow provides a solution for the creation of deliverables in a period that was once considered impossible. This solution requires a slight reduction in overall quality and a significant reduction in the number of deliverables produced, but it will also reduce the number of pursuit presentations that do not provide any visualizations of the proposed work. Through utilization of the "best practice" process for projects with demanding requirements, a total of $1,437.19 and 33.88 hours were saved when compared to the "best practice" workflow for projects with average requirements. When compared to the traditional workflow, the "best practice" process for projects with demanding requirements saves approximately $2,748.39 and 64.79. These statistics, coupled with the fact that the proposed process allows BIM designers to take on extremely demanding projects in a short timeframe, is enough to conclude that the proposed "best practice" workflow provides significant benefits to projects with demanding time requirements and budgetary constraints.

CHAPTER 5: DISCUSSION

This chapter aims to provide a subjective interpretation of the results and conclusions presented in the last chapter. The primary meaning of this chapter is to provide nuanced analysis of the proposed "best practice" workflow and all of the related processes. For context, this chapter will begin with a summary of both the findings and conclusions presented in the previous chapter. Following this summary, the discussion will then interpret these results, identify key contributions, outline any limitations of the study, and provide suggestions for future research topics. The hope is that this section can spark meaningful conversation amongst researchers and provide inspiration for further studies that may improve upon both the "best practice" workflow presented throughout this research and other areas within the AEC industry. This chapter will also culminate in the overall conclusion of this work and will provide a final determination on the success of this study.

5.1 SUMMARY OF RESEARCH FINDINGS

To summarize the key findings presented in the previous section, the following information has been provided based on comparisons to the traditional workflow:

I. For PBC WTP 2: It can be determined that, though the utilization of the proposed "best practice" workflow, the time commitment for producing the required deliverables was reduced by 14.14 hours. This time reduction resulted in an overall savings of approximately $599.82.

II. For PBC WTP 2: The decrease in time requirement allowed for the development of a supplemental deliverable package that included rendered section cuts, an executable presentation file, a VR environment, a live model for demonstration purposes, and supplemental AI generations. These deliverables only increased the time commitment of the proposed workflow by 1.74 hours and cost around $73.81 to produce. This still reflects a total time savings of 12.4 hours and total cost savings of $526.01.

III. For PBC WTP 2: The decrease in tedious modeling tasks provided by the "best practice" workflow allowed for an increased attention to detail during the modeling process, which resulted in an increase in quality of the final deliverable package.

IV. For Concord Hillgrove: Based on average project requirements, the proposed "best practice" workflow reduced the time commitment for producing the required deliverables by 30.91 hours. This time reduction resulted in an overall savings of approximately $1,311.20.

V. For Concord Hillgrove: Based on demanding project requirements, utilization of the "best practice" workflow reduced the time commitment for producing the required deliverables by 64.79 hours with a slight reduction of overall quality. This time reduction resulted in an overall savings of approximately $2,748.39.

5.2 SUMMARY OF RESEARCH CONCLUSIONS

To summarize the conclusions provided in the previous chapter, the following claims have been supported by the research conducted for this study:

I. The CAD Mapper method is definitively the most effective method for topographic surface creation. When compared to the traditional method, this method is 3.48 times faster and provides a cost reduction of approximately 71.27%.

II. The parametric library method provides extensive benefits to the creation of visualization models through eliminating the need to develop families for each piece of equipment.

When compared to the traditional method, this method is 42 times faster and provides a cost reduction of 97.61% per instance placed.

III. Due to the reduction of the LOD required for proposed structures, AI image and video generation provide an opportunity for a 69.01% reduction of time commitment and cost. This time reduction comes with the caveat that a smaller number of less controllable deliverables will be provided, when compared to deliverables provided utilizing high LOD modeling.

IV. Enscape provides better performance on live processes that are more prone to performance issues, while Twinmotion provides better performance on production of high-quality deliverables. The one exception to this is the fact that Enscape performs better at creating rendered section cuts than Twinmotion.

V. At the current time, Autodesk Workshop XR and Resolve BIM would be too difficult to implement on a large scale for pursuit interviews due to the requirement that all attendees have access to a headset, VR hesitance amongst the working population, and the lack of visual aesthetic of the models within each application.

VI. Although collaborative VR experiences cannot currently carry a pursuit interview, it could have an immense impact on these interviews in the near future.

VII. Through the utilization of the “best practice” process for projects with average requirements on both case studies, a total of $1,837.21 and 41.31 hours were saved, when compared to the results of the traditional workflow. These statistics alone reflect the overall benefit of the “best practice” workflow.

VIII. The utilization of the “best practice” process for projects with average requirements allows for the production of supplemental deliverable packages within the initial time constraints of each project.

IX. The proposed “best practice” workflow for projects with demanding requirements allows designers to take on pursuit projects with constraints that once rendered the development of required deliverables impossible.

X. Through the utilization of the “best practice” process for projects with demanding requirements on the Concord Hillgrove case study, a total of $2,748.39 and 64.79 hours were saved, when compared to the results of the traditional workflow. These statistics alone reflect the overall benefit of the “best practice” workflow.

5.3 DISCUSSION

This section aims to provide further insight into the interpretations, implications, and limitations of the results presented in this study. This section will begin by providing a thorough explanation of the key meaning of the results and a subjective determination on the success of this study. After the results have been analyzed and interpreted, this section will discuss the impact that this study has on the AEC industry, on both a focused and broad scale. These implications aim to provide a deeper understanding of the significance of the findings and conclusions presented in the previous chapter. It is also imperative that this section provides a critical assessment of the limitations of this study. Through this assessment, the goal is to identify key areas of the study that can be strengthened through continued study and provide inspiration for future investigations.

5.3.1 INTERPRETATION

At the onset of this study, the main goal was to develop a "best practice" workflow for the BIM visualization of water treatment projects to be utilized in pursuit interviews. The purpose of this proposed workflow was to reduce both the time and cost of developing these BIM visualization deliverables, while also preserving the final quality that has come to be expected of these deliverables. Through the usage of rapid modeling techniques, improved visualization workflows, and emerging technologies, a "best practice workflow was developed and evaluated through the development of deliverable packages for two different projects: PBC WTP 2 Improvements and Concord Hillgrove GAC Upgrade.

Through traditional visualization workflows, these projects had a combined total cost of $8357.59 (based on a labor burden rate of $42.42/hr) and took approximately 197.02 hours to complete. Based on the results of these case studies, it was then determined that when average project requirements are assumed, the proposed workflow provided cost savings of $1,837.21 and time reduction of 41.31 hours across both projects. Therefore, on average, the proposed workflow resulted in a 20.97% decrease in both the time commitment and the final cost of producing the desired deliverable packages for each project. Through these savings, the overall capital risk of losing a pursuit is reduced by $1,837.21 and less of the BIM designer's time was spent on an unsuccessful venture. In regard to quality, this workflow automates many of the tedious tasks associated with the creation of the BIM models for visualization projects, which allows the BIM designer to spend more time developing the desired level of detail. This increased the focus on the level of detail produced deliverable packages with an increased overall quality and an increased number of deliverables. For context, compare the resulting deliverable package for the traditional workflow (appendix B) to that of the deliverable packages developed utilizing the "best practice" process for projects with average time requirement (appendices C and D).

Regarding projects with demanding requirements, when these constraints were assumed for the Concord Hillgrove case study, the proposed workflow provided cost savings of $2,748.3 and time reduction of 64.79 hours. Therefore, on average, the proposed workflow resulted in a 67.12% decrease in total time commitment and cost when developing a deliverable package under the assumed constraints. This overall reduction was achieved through the utilization of AI workflows for generations of both rendered images and videos. While, on average, these AI generations do not provide the same level of quality (see appendix E), the time reduction created through the utilization of these tools provides opportunities to accept visualization projects under constraints that were once considered impossible. Through the reduction of the deliverable package to its simplest form, still images and videos, these AI workflows offer viable solutions for the reduction of overall cost and time commitment, thus creating a low risk, high reward workflow. Based on this assessment, it is recommended that this workflow should be utilized when chances of winning a pursuit interview are low and the risk of losing the capital required to develop any deliverables is high.

As mentioned at the beginning of this section, the intended purpose of this study was to develop a "best practice" workflow that reduced the overall time commitment and cost of developing visualization deliverable packages for pursuit interviews. Through the interpretations of the findings and conclusions presented in the previous chapter, it can be concluded that conducted study successfully developed an effective "best practice" workflow that can be adopted into projects of varied scope.

5.3.2 IMPLICATIONS

This section will contain nuanced discussion of the intriguing implications of this study and the impacts that it has on the AEC industry. These range from impacting specified areas of the BIM design process to having broad implications across the entire industry. This section will offer this discussion in a structured format that is aimed at providing an optimized reading experience.

Contributions to a Limited Research Catalogue

During the literature review conducted for this project, it was noted that there was an extremely limited catalogue of research available regarding BIM visualizations and development of visualization deliverables for project pursuits. Through extensive research, only a select few of the academic sources examined in this study were related to BIM visualizations. Based on this same research, readily available academic sources that examines the usage of these BIM visualizations for the development of deliverable packages for pursuit projects are extremely sparse. This research will assist in populating this niche topic for future researchers and will aim to inspire future studies that expand the library of available literature on this topic.

Increased Ability to Produce Budget Friendly High-Quality Deliverables for Pursuits

Through the increased efficiency offered by the "best practice" workflow, the ability to produce high quality deliverables for pursuit projects is also increased. In some cases, pursuit teams will opt to forego the development of BIM visualizations due to project constraints that restrict the ability to produce these deliverable packages. In the competitive environment of pursuing design projects, this decision can greatly impact the odds of a successful pursuit interview. This research provides solutions in response to these common constraints that reduce the overall time and cost commitment by 20.97% and 67.12%, respectively. The hope is that this research will provide BIM designers with tangible evidence of the efficacy of these solutions that can alleviate any concerns that a pursuit team may have.

Increased Access of BIM Visualization for Project Pursuits

In many cases, the pursuit process is innately more difficult for smaller design firms that do not have the same resources available as their competitors. This lack of resources can lead to severe disadvantages throughout the pursuit process, especially in the development of presentation deliverables. Due to the overall cost and skill required to develop these visualization deliverables, many smaller firms opt to forego this process as it is considered supplemental and unnecessary. While it can be agreed that, in most cases, the merit of the design team is the largest contributing factor to successful pursuits, these visualizations can often aid the client in deciding between two firms with similar qualifications. Through the research conducted in this study, the overall resource requirement and skill gap of creating these visualizations was reduced, which increases the overall access of these deliverables. It is hypothesized that, through the aforementioned reductions, the findings of this research will increase any given design firm's ability to produce high-quality BIM visualizations for every pursuit interview.

Reduction of Initial BIM Effort During the Design Process

An additional benefit of the findings of this study is the overall reduction of the required BIM effort in the initial stages of the design process. After a design project is won, the first key BIM task is the development of models for all existing structures on the site for the first design submittal. Through the proposed visualization process, a highly detailed model of the proposed project site is developed. These models typically include a preliminary site layout, key selections for proposed equipment, exteriors of existing structures, exteriors of proposed structures, and interiors of proposed structures. Therefore, if the "best practice" workflow is utilized during the pursuit phase, the first key BIM task is already completed upon the award of a given project. This provides the added benefit of expediting the delivery of the 30% design submittal, which is typically the first client submittal.

BIM Visualization as a Public Marketing Tool for Projects

For projects with implications for public relations or a need for extended marketing campaigns, the process of creating high-level BIM visualizations through the proposed workflow also provides clients with useful marketing materials upon the award of the project. One example of this benefit is provided by a recent pursuit project in St. Pete, Florida in which elements of the proposed "best practice" workflow were utilized to produce visualization deliverables. The project's scope consisted of the design of a proposed pump station on a small lot positioned between two multi-million-dollar residential homes in the coastal town of St. Pete. Throughout the proposal process, the client requested high-level renderings of the proposed design that could be provided to the homeowners to ensure that they were happy with the final aesthetic of the pump station. Examples of the required design visualization are provided in the figures below:

Figure 5.3.2.80: Example 1 of St. Pete Rendered Image Utilized by Client as Marketing Material

Figure 3.2.2.81: Example 2 of St. Pete Rendered Image Utilized by Client as Marketing Material

BIM Visualization for Design Coordination

The proposed workflow also has intriguing implications on the ability to utilize BIM visualizations as a coordination tool, both internally and externally, during the later stages of a design project. From a BIM model manager's standpoint, as a given design progresses the level of effort required to coordinate design changes amongst all disciplines becomes increasingly difficult. In order to reduce this difficulty, many model managers will turn to visual aids to provide context to each coordination issue. This proposed workflow and the associated research provided by this study could be applied to assist in efficiently creating these visual aids based on any given stage of the design process. For example, by utilizing the "best practice" visualization processes, model managers could create BIM visualizations of issues to present during coordination calls or even utilize Autodesk Workshop XR to conduct coordination meetings within the model at a 1:1 scale. This highlights the potential that many of the "best practice" processes presented in this work to be adapted for other purposes that were not expressly addressed throughout this research.

5.3.3 LIMITATIONS

This section will contain a critical evaluation of the major limitations of the key findings and conclusions of this research. The goal of this section is to determine key areas of improvement for future research on the same topic and identify the shortcomings of the research presented in this work. This section will offer this discussion in a structured format that is aimed at providing an optimized reading experience.

Limited Number of Case Studies Provides Less Accurate Average Statistics

The average performance statistics presented in this work are solely based on the two case studies conducted for this project. While these statistics are enough to conclude the effectiveness of the proposed workflow, these averages cannot be applied to projects outside of this study at the current time. Based on the limited sample size, any estimates conducted utilizing the average time and cost data from this study have increased potential for inaccuracy. In order to improve upon this major limitation, more data should be collected and catalogued from future projects that utilize the proposed workflow. Once that a large database of key statistics is developed, then the averages produced could be utilized to more accurately predict the cost and time commitment of any given visualization project.

Limited Application of AI Workflows in Projects That Must Maintain Overall Quality

Based on the needs of any given project, the constraints and requirements can vary significantly. While the proposed "best practice" workflow attempts to address multiple scenarios of varying requirements, it unfortunately cannot be used an all-encompassing guide for every possible visualization project. In the case of projects with demanding requirements, the proposed AI workflow works exceptionally well when pursuit teams will allow a slight reduction in overall quality of the final visualization deliverable package. However, in cases where this overall quality must be maintained, the pursuit team must accept sacrifices in different areas. In order to fully preserve or improve quality, the “best practice” process for projects with average requirements must be utilized instead. This will require an increased pursuit budget to supplement any overtime cost associated with completing projects within limited timelines. In situations where the pursuit budget will not allow for any increase, the project team must accept the reduced quality provided by the proposed AI workflow or proceed into the interview without any visualizations.

5.4 SUGGESTIONS FOR FUTURE RESEARCH

Exploration of Methods to Reduce Model Development Times at HLOD

As noted throughout this research, one of the most time-consuming processes associated with the visualization of BIM models is the development of existing and proposed model elements to an elevated level of detail. According to the findings of the case studies, over 76.27% of the time required to complete the deliverable packages was associated with miscellaneous modeling tasks associated with increasing the desired level of detail in the BIM model. If further research studies could provide methods to reduce the time commitment associated with these tasks, there is potential for drastic time and cost reduction in the process of developing the desired visualization deliverables.

Exploration of Scan to BIM Workflows

Whilst researching the LiDAR method for topographic surface generation, many intriguing Scan-to-BIM workflows were uncovered. Scan-to-BIM workflows refer to the ability to conduct a LiDAR survey of an existing structure and then convert the acquired scan data into BIM data either through a generative process or a manual process. The general process of Scan-to-BIM typically results in a complete BIM model of the surveyed structure. While these workflows have recently become more common within the AEC industry, there is still potential to uncover many intriguing uses for this concept. If future research studies could further explore and provide a "best practice" workflow for the various uses of Scan-to-BIM principles, this would provide significant impact to the AEC industry.

Development of Company Specific AI Models for BIM Visualization

As AI technologies continue to improve, many companies are tasked with determining the ramifications of the use of these technologies to improve their exiting workflows. In many cases, AI solutions utilize a majority of data input by the user as training data to improve the model. This could cause legal issues if a company were utilizing a commercially available AI model, such as EvolveLAB's Veras or Runway ML, to visualize projects that contain proprietary information. Therefore, it is important to explore developing company specific AI models for model visualization that keep all training data within the confines of the company. These company specific AI models would also help companies better control the quality of final deliverables and the overall aesthetic of the images generated or videos. If future research could delve into the process of creating these company specific AI models, this would provide a major contribution to any AEC firm looking to implement AI workflows.

5.5 CONCLUSION

In conclusion, the research study conducted throughout this thesis provides key findings and conclusions that support the successful development of the proposed "best practice" workflow for the production of BIM visualization deliverables associated with project pursuits. The "best practice workflow was evaluated utilizing two case studies: The Palm Beach County Water Treatment Plant 2 and the Concord Hillgrove GAC Upgrade project pursuits. Based on the average results of the two conducted case studies, it can be concluded that for projects assuming average requirements, the utilization of the proposed best practice workflow reduces the overall cost and time commitment of developing the required deliverables by 20.97%, when compared to the results of the traditional workflow. An alternate process was also provided to be utilized in projects with demanding requirements. Based on the Concord Hillgrove case study, in which this alternative process was utilized, proposed workflow resulted in a 67.12% reduction of both cost and time commitment. These cost reductions associated with each “best practice” process are provided while also ensuring a desired level of quality is achieved. Although there is still potential for improvement of this proposed workflow through the reduction of time requirements associated with the modeling tasks required to develop models to a higher level of detail, it can still be concluded that the proposed “best practice” workflow provided the intended benefit of this study. Based on the comprehensive information provided throughout this study, it can be recommended that the proposed “best practice” workflow should be adopted as the current standard for the production of required visualization deliverables for water and wastewater treatment pursuit projects.

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APPENDIX A: DYNAMO SCRIPTS FOR PARAMETRIC FAMILY MANIPULATION

In order to provide readers with context regarding the Dynamo scripts that were developed for this study, the following pages will contain images that have been exported from the Dynamo workspace that showcase the scripts that were created for each parametric family. The script for each family has been color coded to allow the reader to better understand the function of each script group. Script groups in blue are pulling the family that the user selects in the Dynamo Player's drop-down menu into the dynamo workspace, while scripts in green are assigning the parameters of each family based on the user's input in the subsequent prompts. The outputs from these color-coded script groups are then connected to the proper inputs of the "Elements.SetParameterByNameType" node from the *Rhythm* Dynamo package in order to assign the parameters to the selected family.

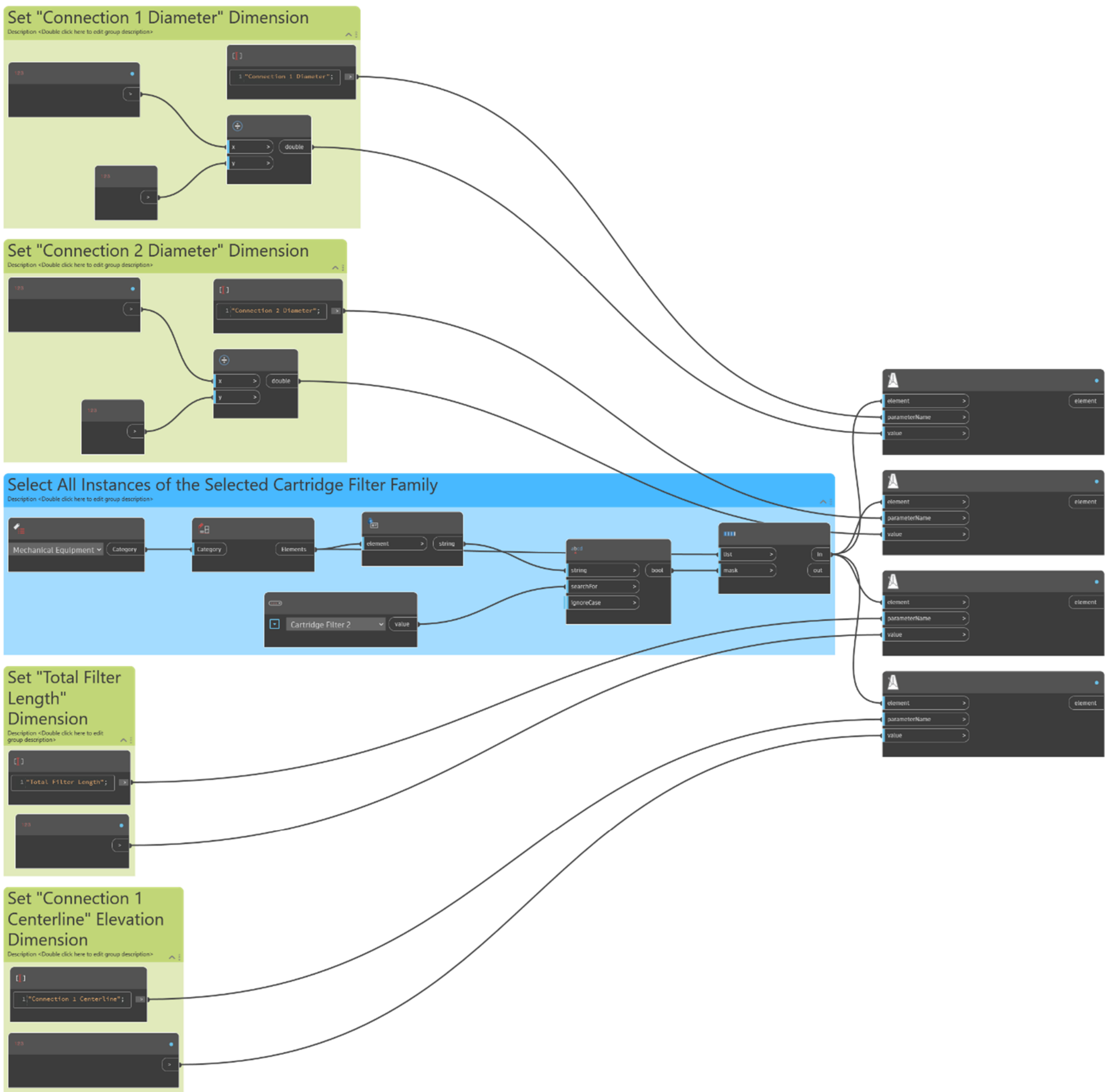

Figure A.82: Dynamo Script for Manipulating Cartridge Filter Family

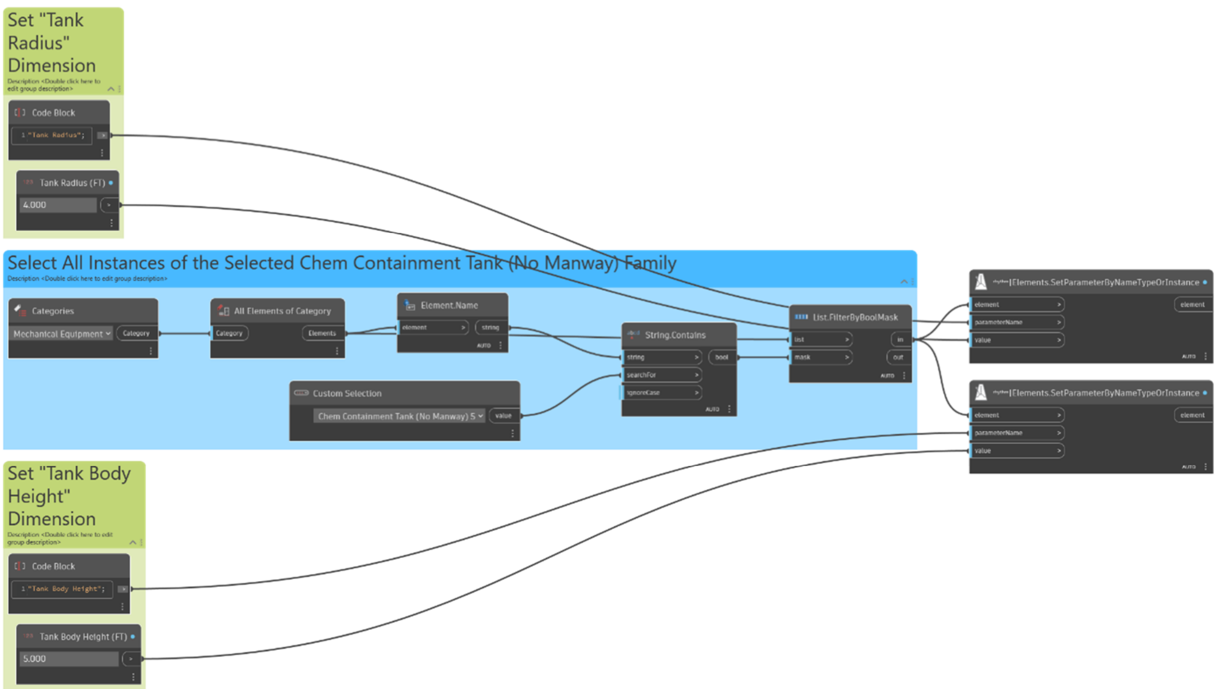

Figure A.83: Dynamo Script for Manipulating Chem Containment Tank (No Manway) Family

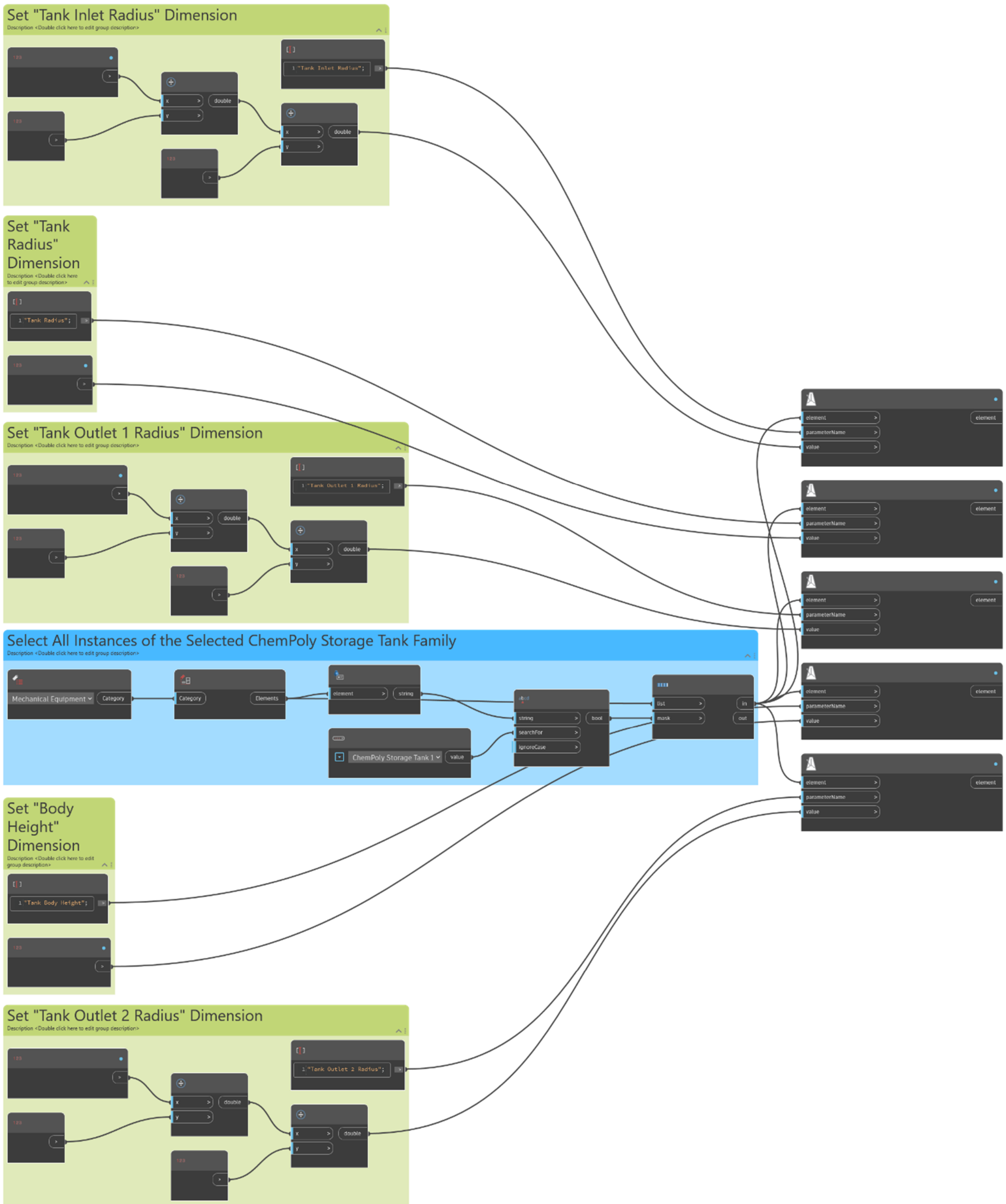

Figure A.84: Dynamo Script for Manipulating ChemPoly Storage Tank Family

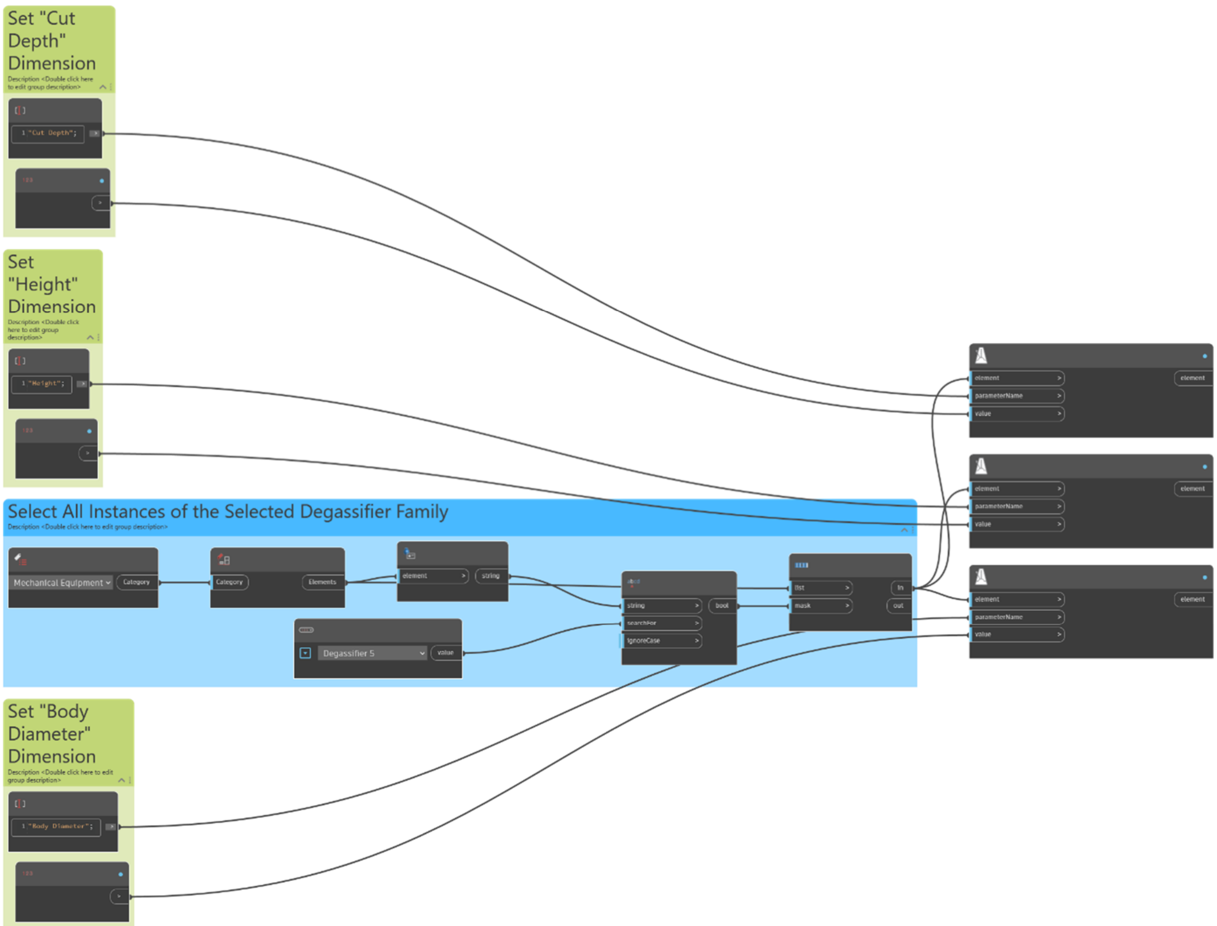

Figure A.85: Dynamo Script for Manipulating Degassifier Family

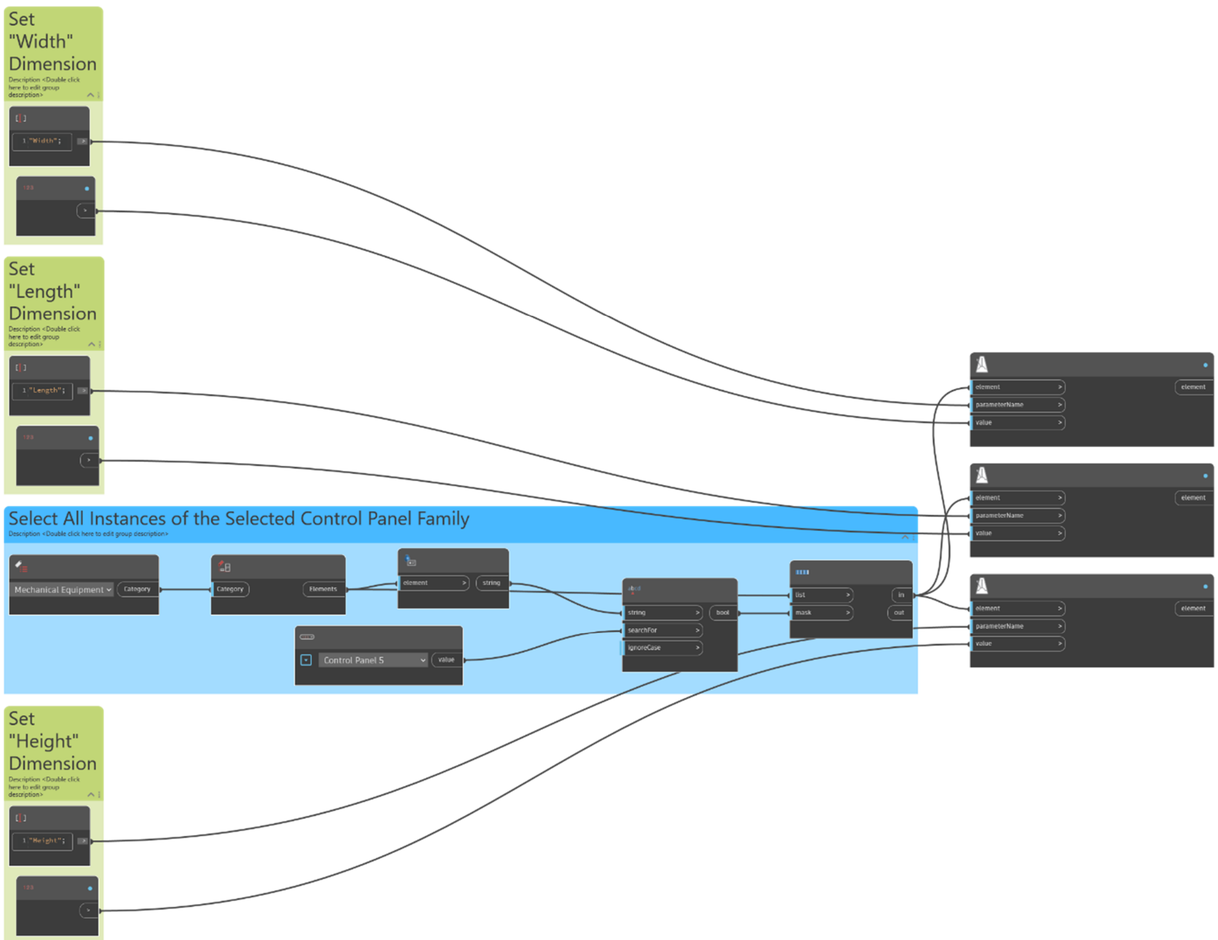

Figure A.86: Dynamo Script for Manipulating Control Panel Family

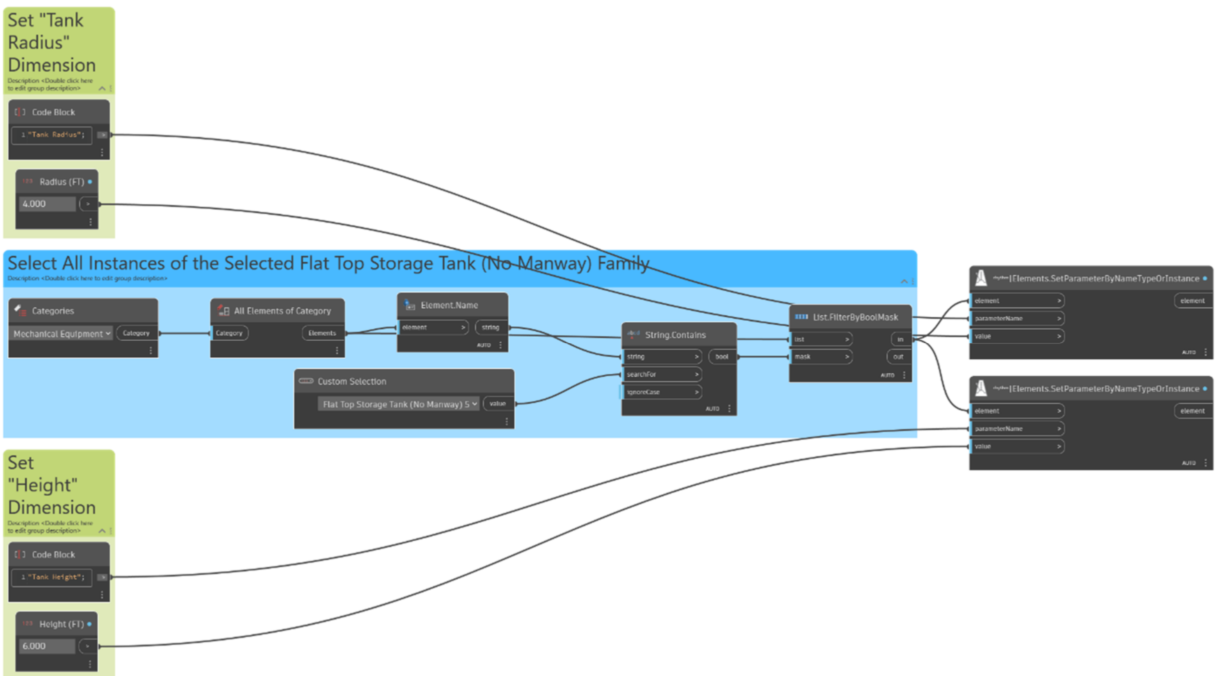

Figure A.87: Dynamo Script for Manipulating Flat Top Storage Tank (No Manway) Family

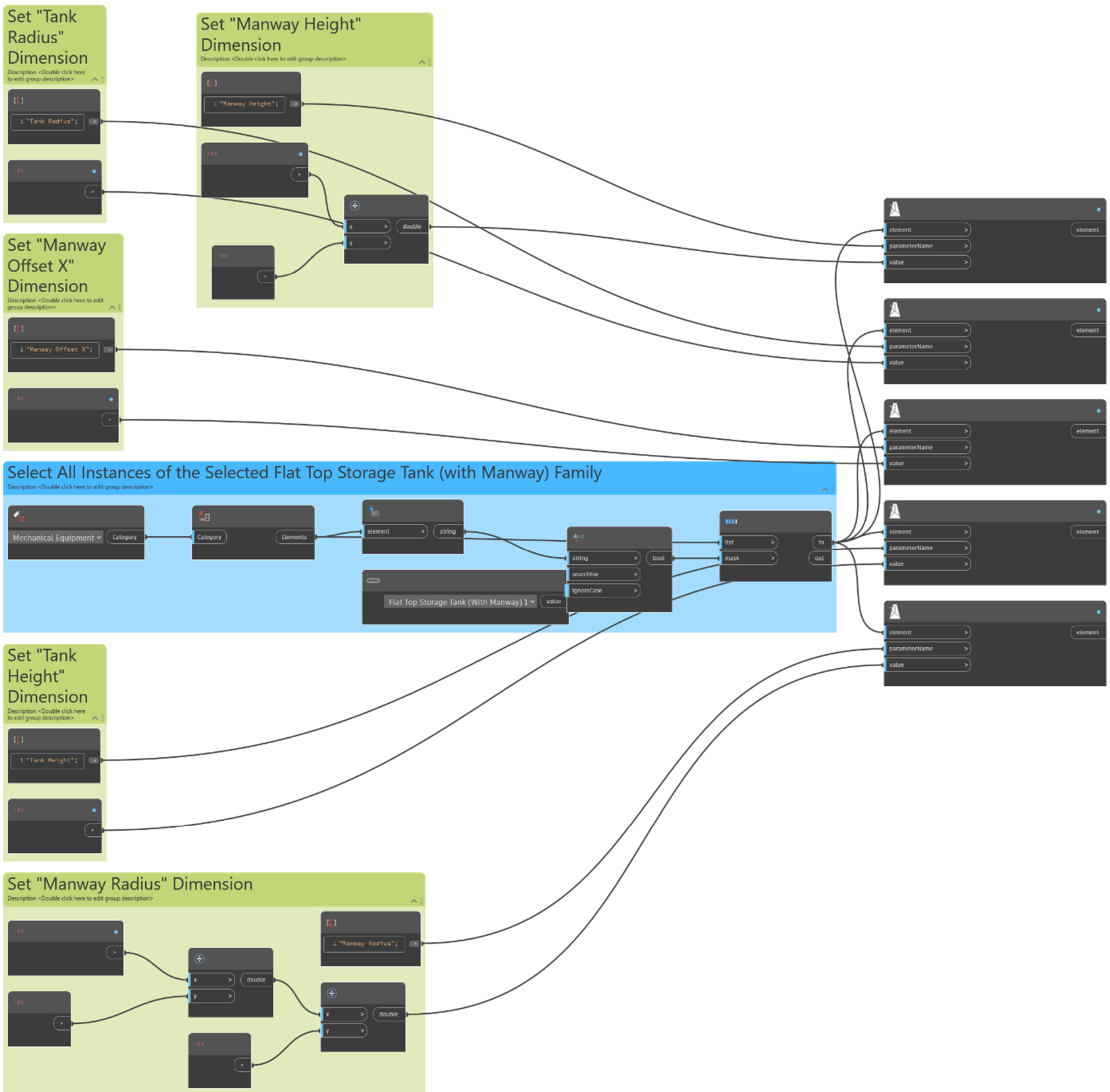

Figure A.88: Dynamo Script for Manipulating Flat Top Storage Tank (with Manway) Family

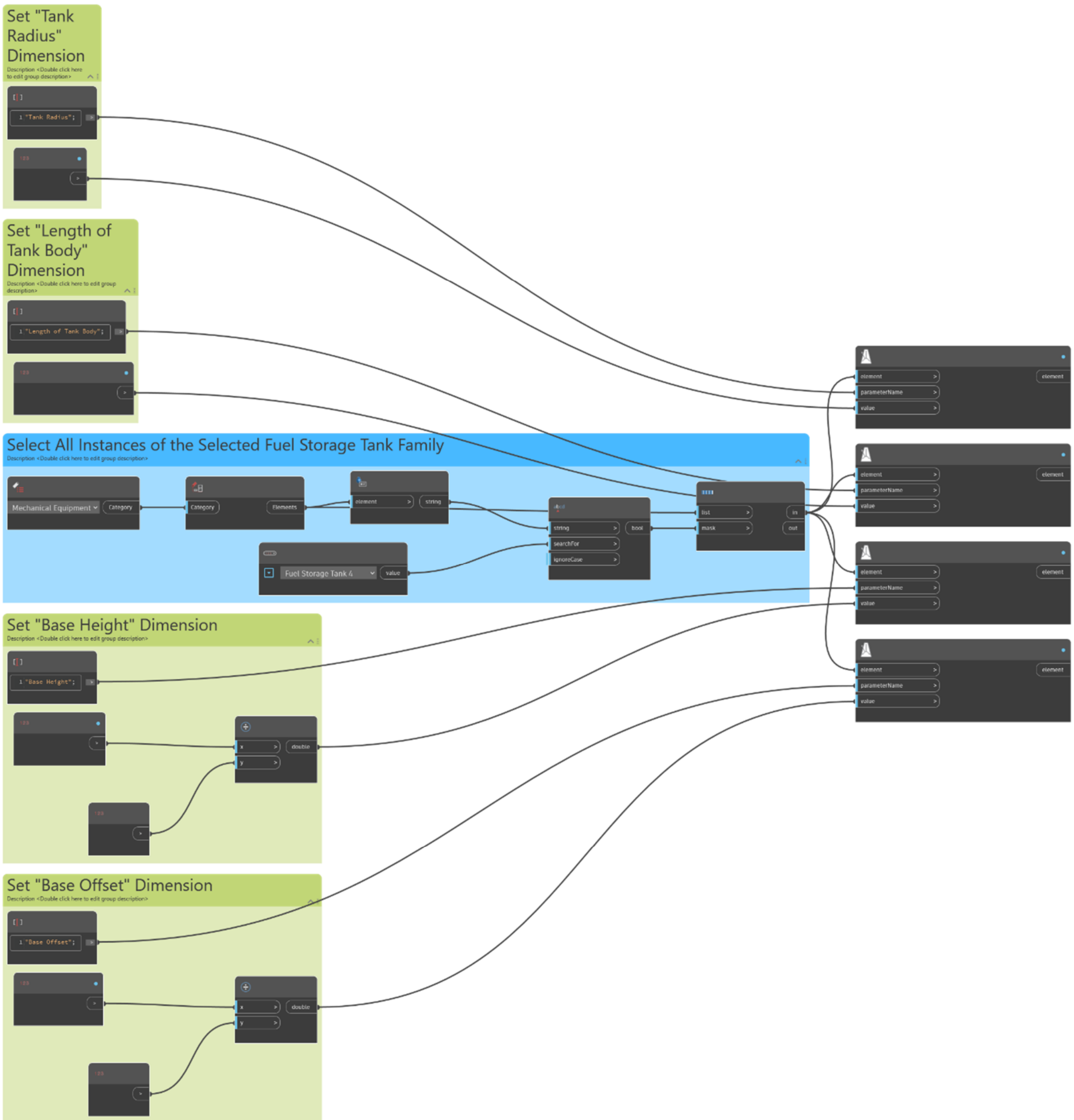

Figure A.89: Dynamo Script for Manipulating Fuel Storage Tank Family

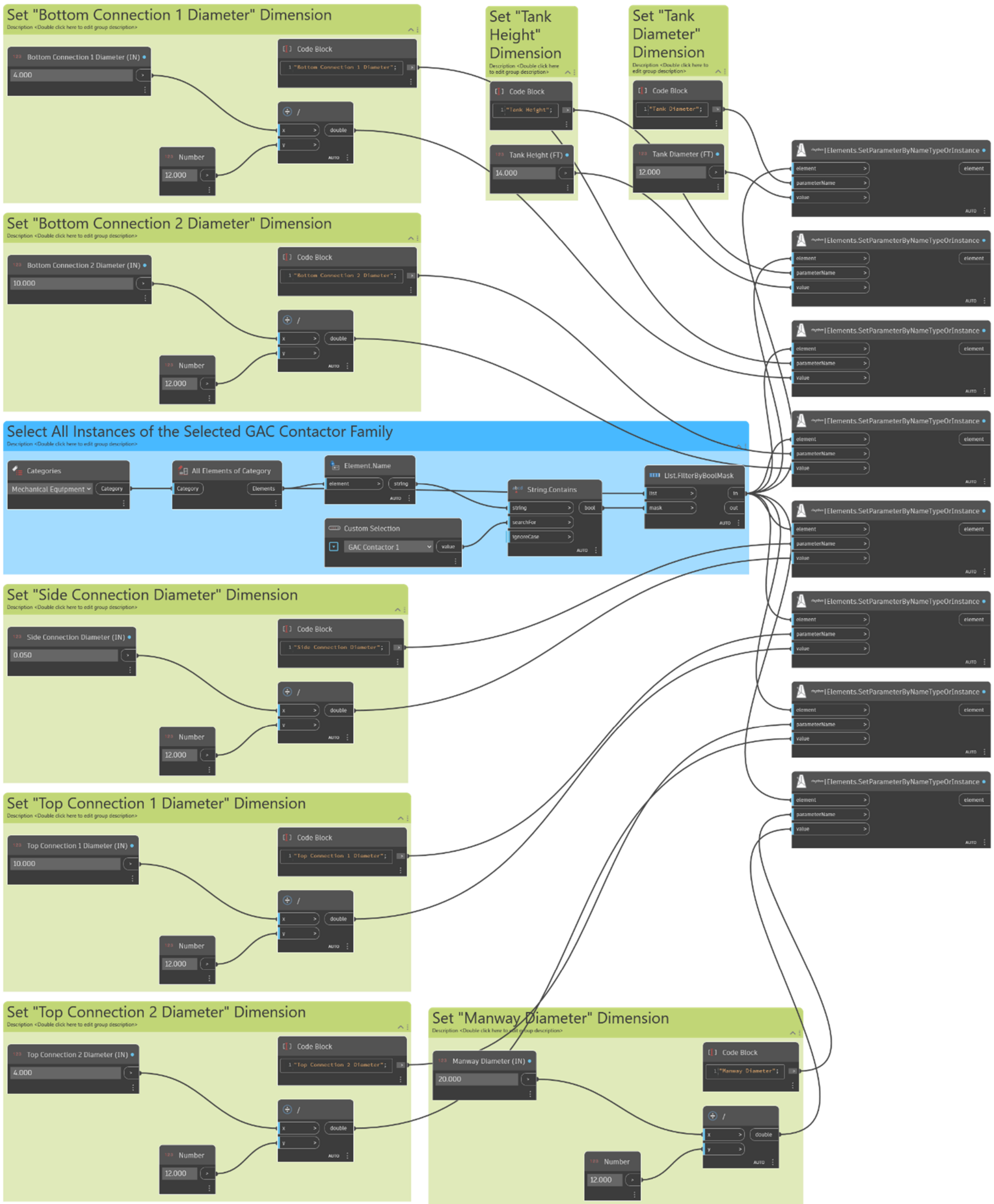

Figure A.90: Dynamo Script for Manipulating GAC Contactor Family

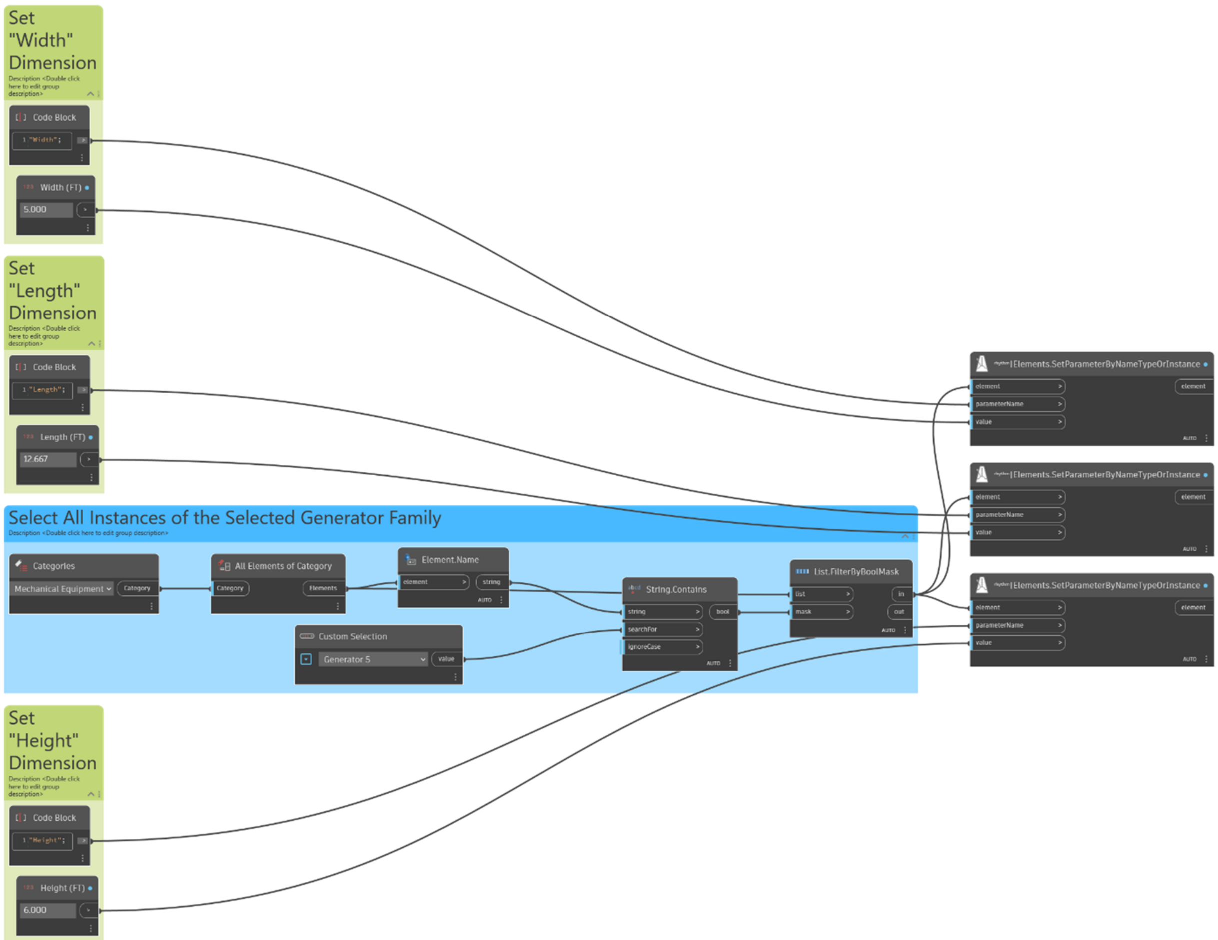

Figure A.91: Dynamo Script for Manipulating Generator Family

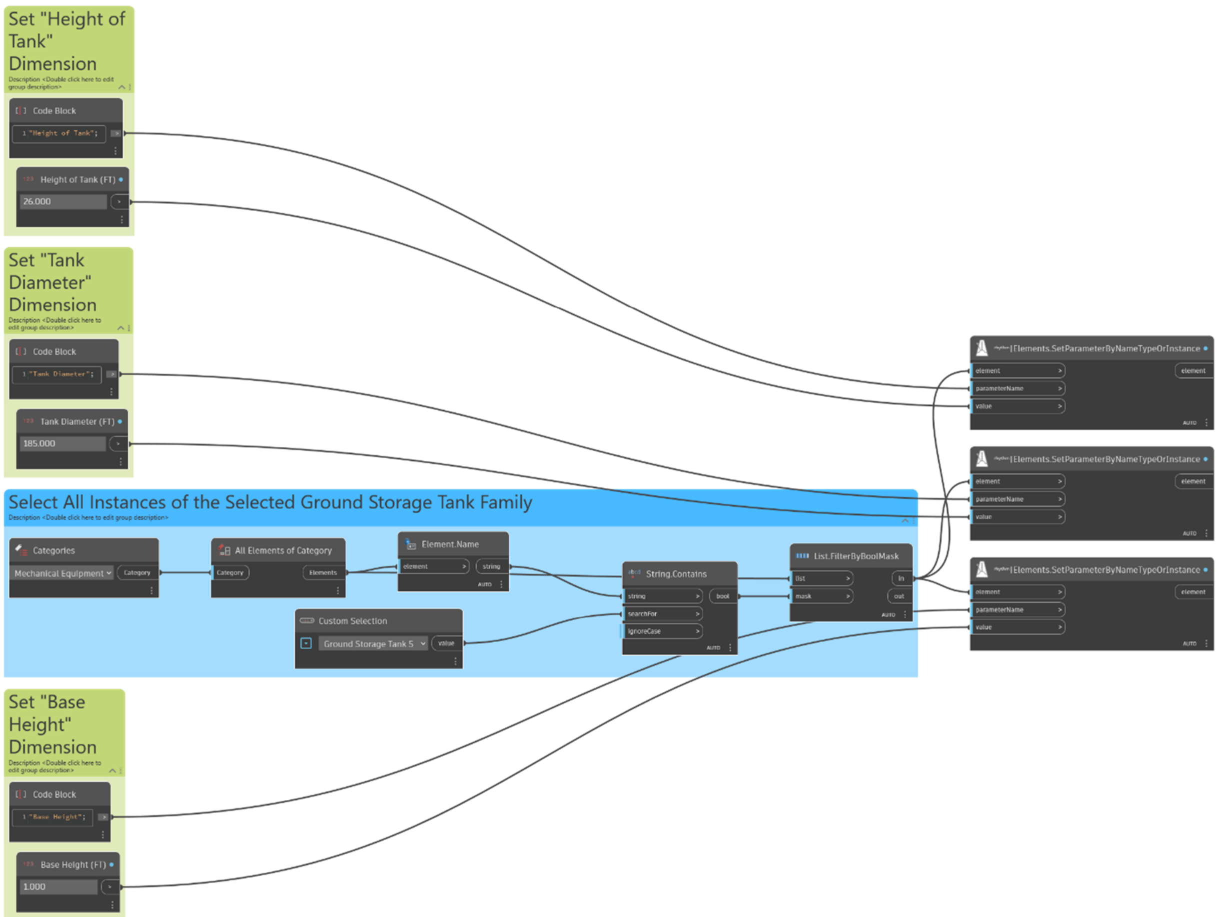

Figure A.92: Dynamo Script for Manipulating Ground Storage Tank Family

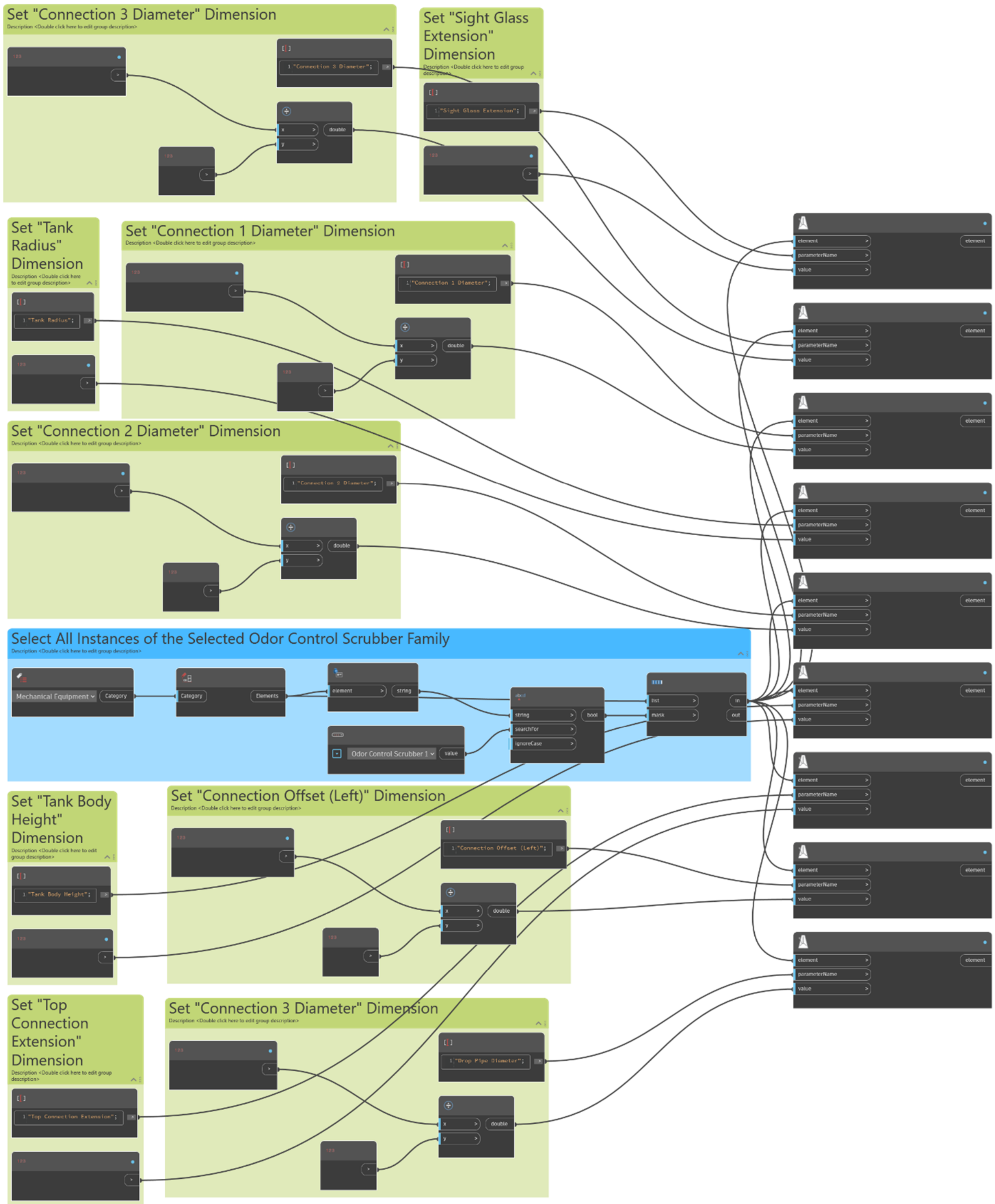

Figure A.93: Dynamo Script for Manipulating Odor Control Scrubber Family

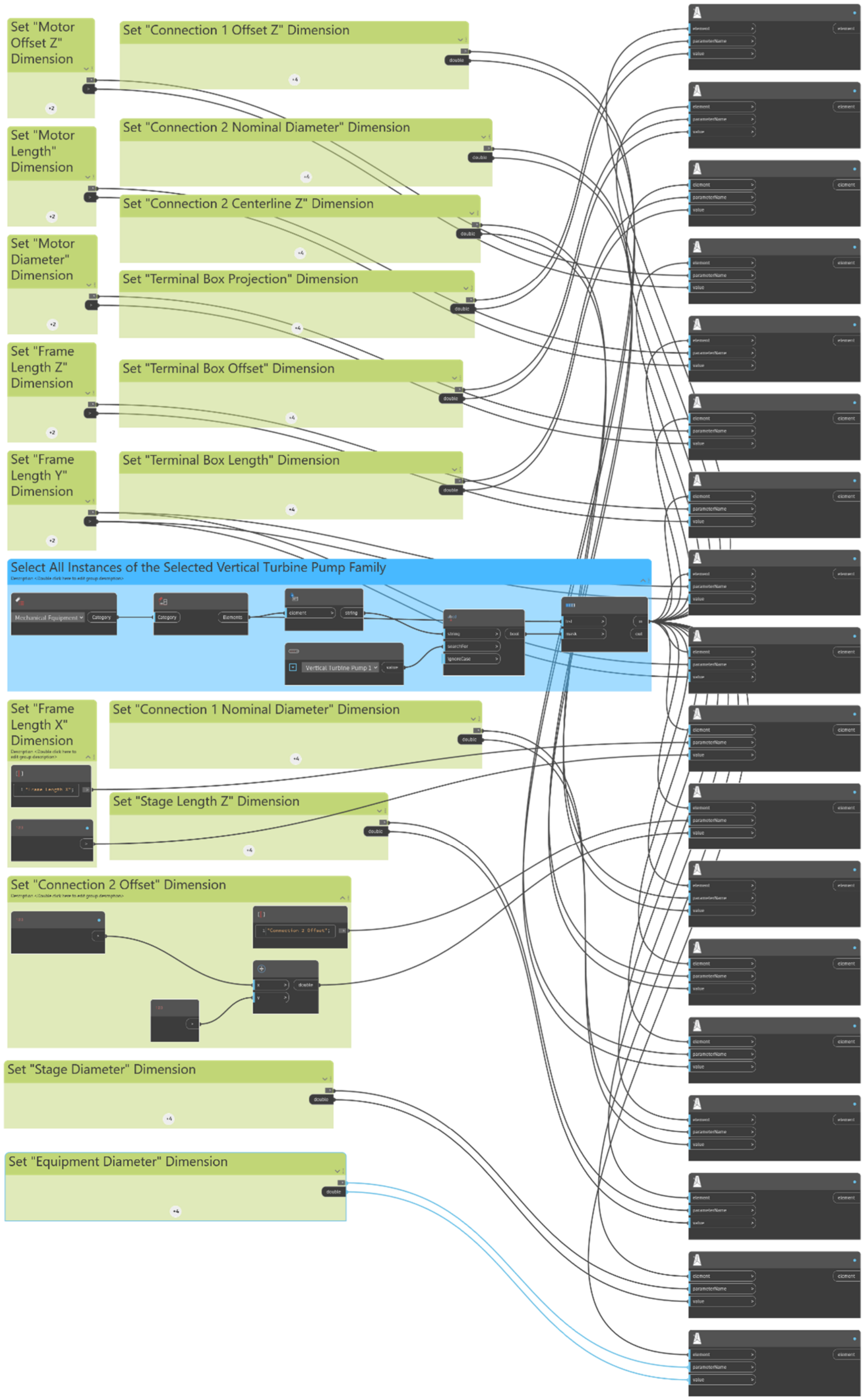

Figure A.94: Dynamo Script for Manipulating Vertical Turbine Pump Family

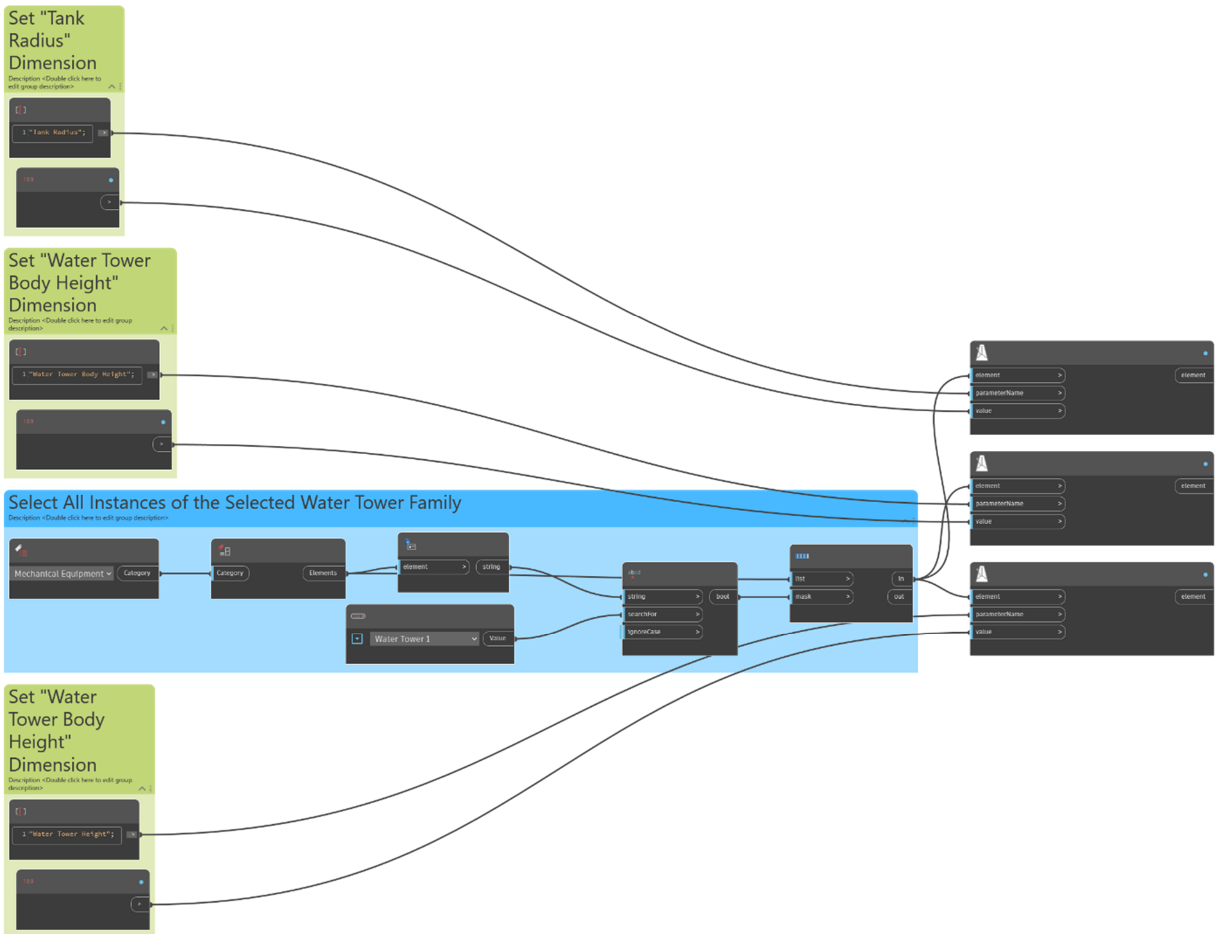

Figure A.95: Dynamo Script for Manipulating Water Tower Family

APPENDIX B: PBC WTP 2 TRADITIONAL WORKFLW DELIVERABLE PACKAGE

In order to provide readers with context regarding the visualization deliverable package developed for the PBC WTP 2 project pursuit utilizing the traditional workflow for average projects (outlined in table 3.2.7.3), the following pages contain images of each of the deliverables developed for this methodology of the PBC WTP 2 case study:

Figure B.96: PBC WTP 2 Overall Image 1 from Traditional Workflow

Figure B.97: PBC WTP 2 Overall Image 2 from Traditional Workflow

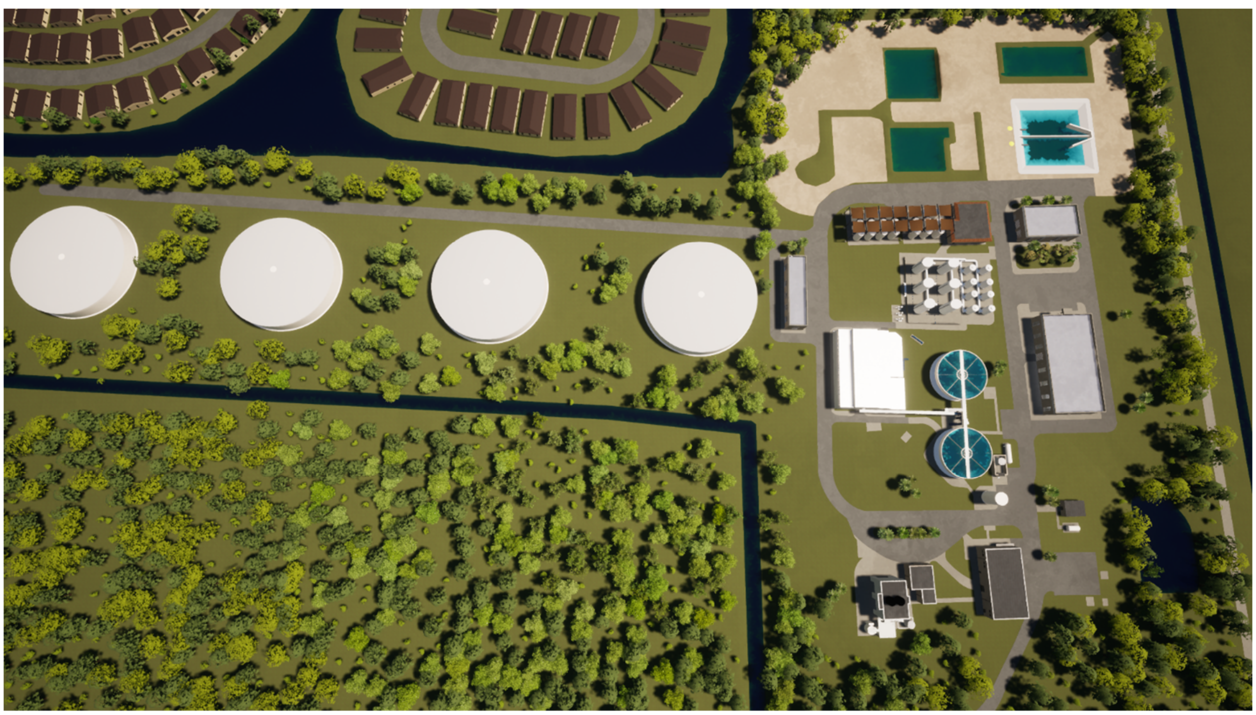

Figure B.98: PBC WTP 2 Overall Image 3 from Traditional Workflow

Figure B.99: PBC WTP 2 Overall Image 4 from Traditional Workflow

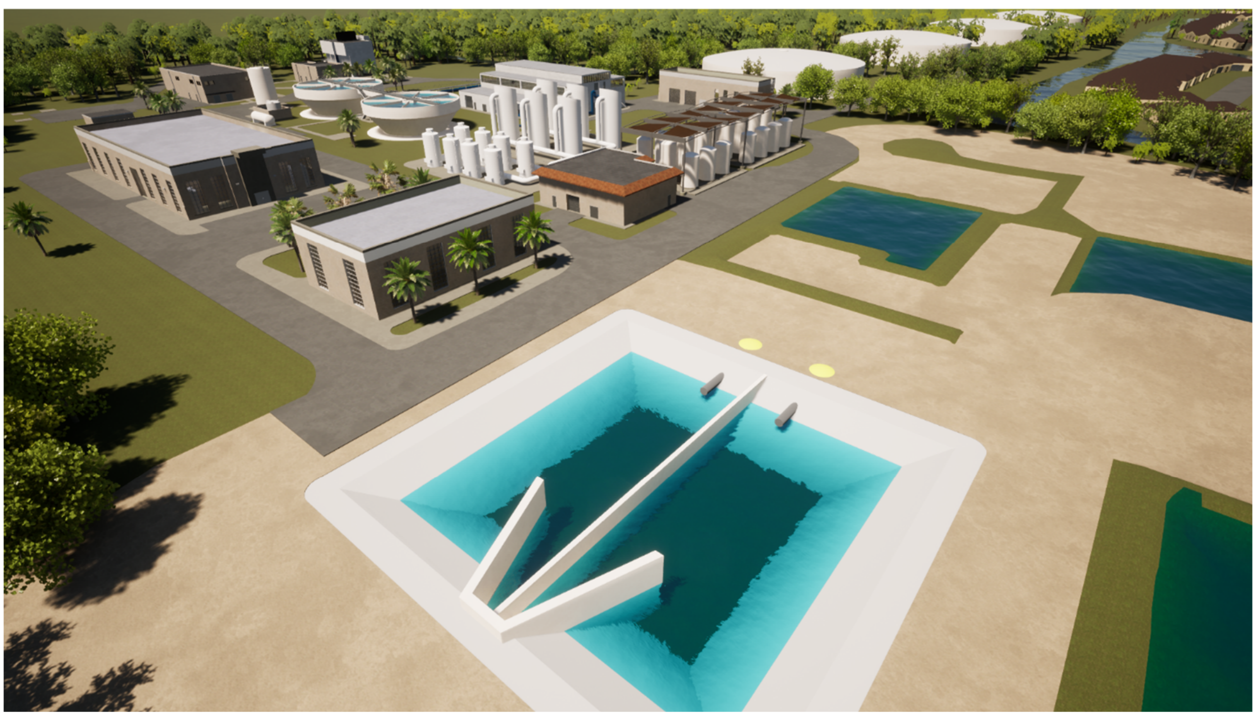

Figure B.100: PBC WTP 2 Overall Image 5 from Traditional Workflow

Figure B.101: PBC WTP 2 Image of Proposed Buildings from Traditional Workflow

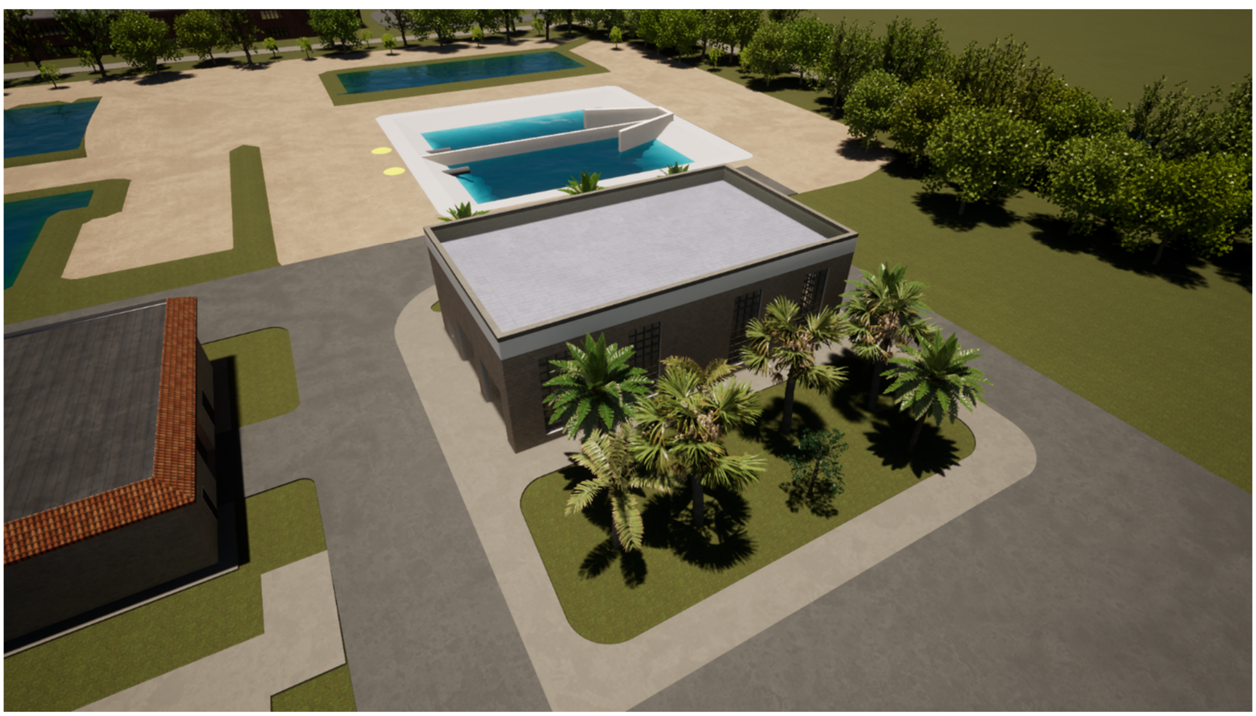

Figure B.102: PBC WTP 2 Image of Generator Building from Traditional Workflow

Figure B.103: PBC WTP 2 Image of Nanofiltration from Traditional Workflow

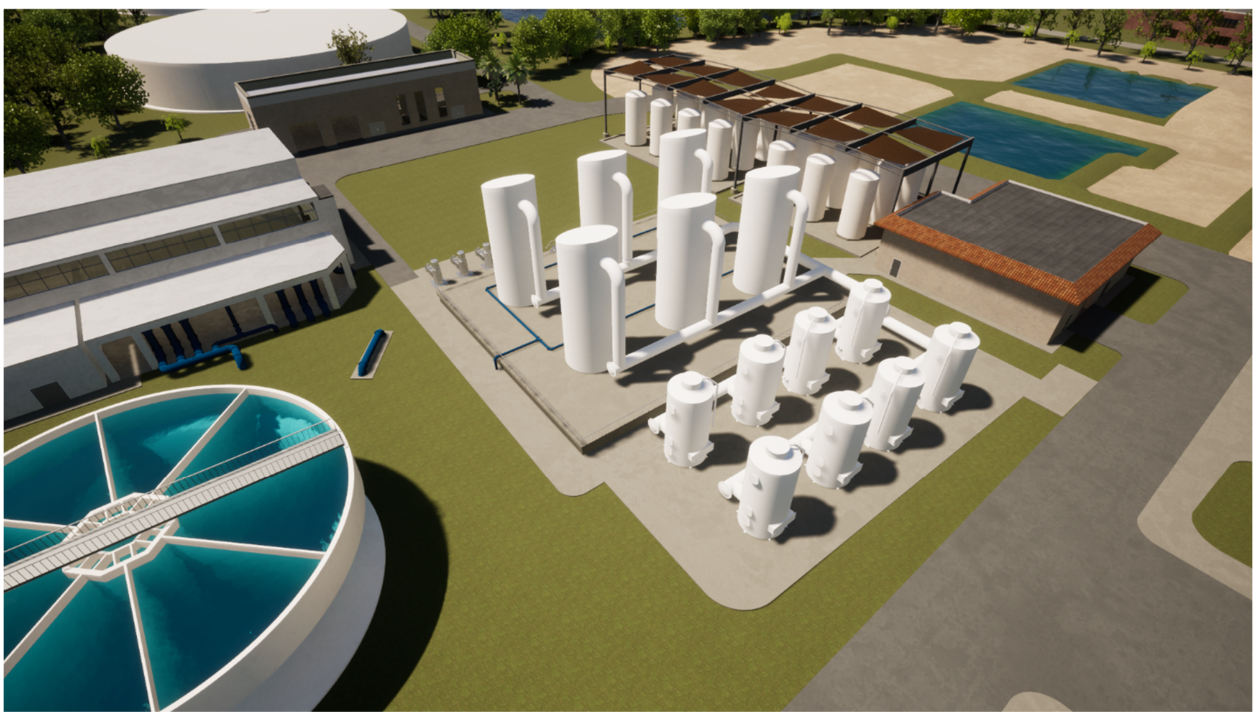

Figure B.104: PBC WTP 2 Image of Proposed Structures from Traditional Workflow

Figure B.105: PBC WTP 2 Image of HSPS from Traditional Workflow

Figure B.106: PBC WTP 2 Plant Flythrough Video from Traditional Workflow

Figure B.107: PBC WTP 2 HSPS Video from Traditional Workflow

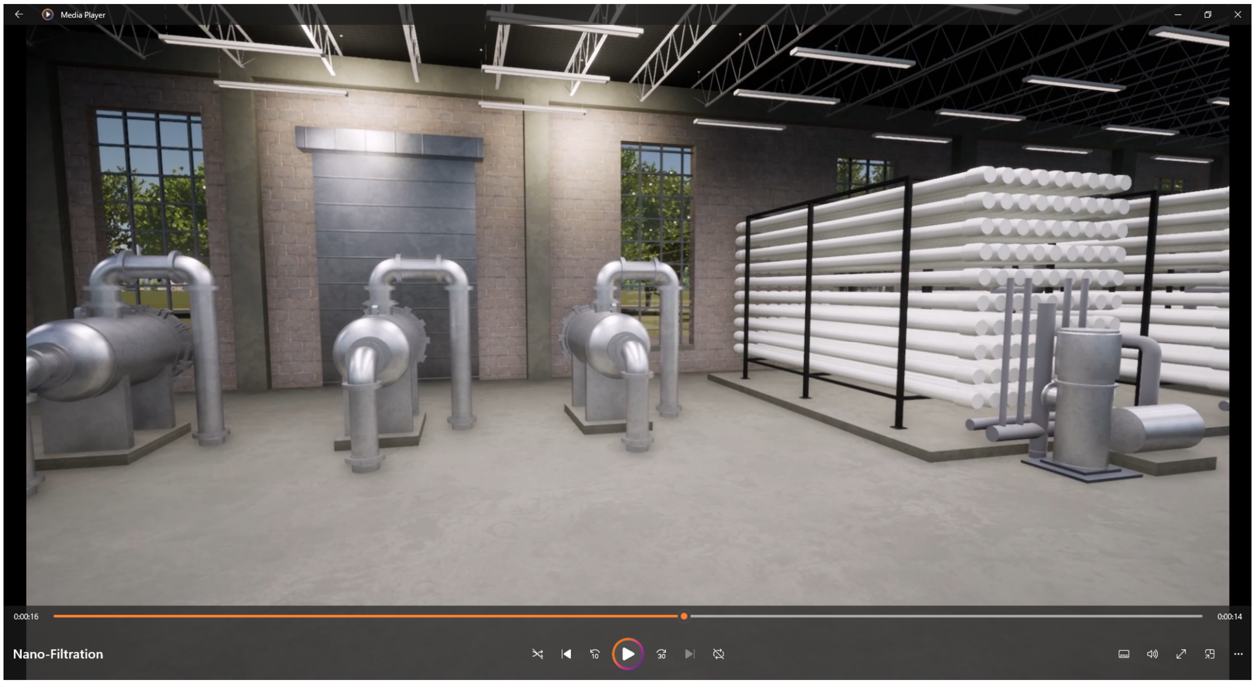

Figure B.108: PBC WTP 2 Nanofiltration Video from Traditional Workflow

Figure B.109: PBC WTP 2 Live Demonstration from Traditional Workflow

APPENDIX C: PBC WTP 2 “BEST PRACTICE” WORKFLOW DELIVERABLE PACKAGE

In order to provide readers with context regarding the visualization deliverable package developed for the PBC WTP 2 project pursuit utilizing the proposed “best practice” workflow for average projects (outlined in table 3.2.7.1), the following pages contain images of each of the deliverables developed for this methodology of the PBC WTP 2 case study:

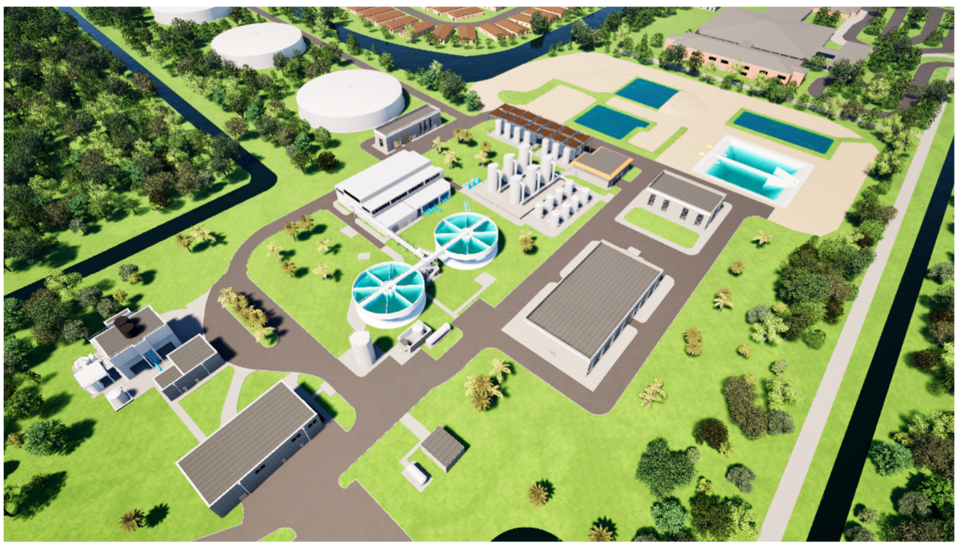

Figure C.110: PBC WTP 2 Overall Image 1 from "Best Practice" Workflow

Figure C.111: PBC WTP 2 Overall Image 2 from "Best Practice" Workflow

Figure C.112: PBC WTP 2 Overall Image 3 from "Best Practice" Workflow

Figure C.113: PBC WTP 2 Overall Image 4 from "Best Practice" Workflow

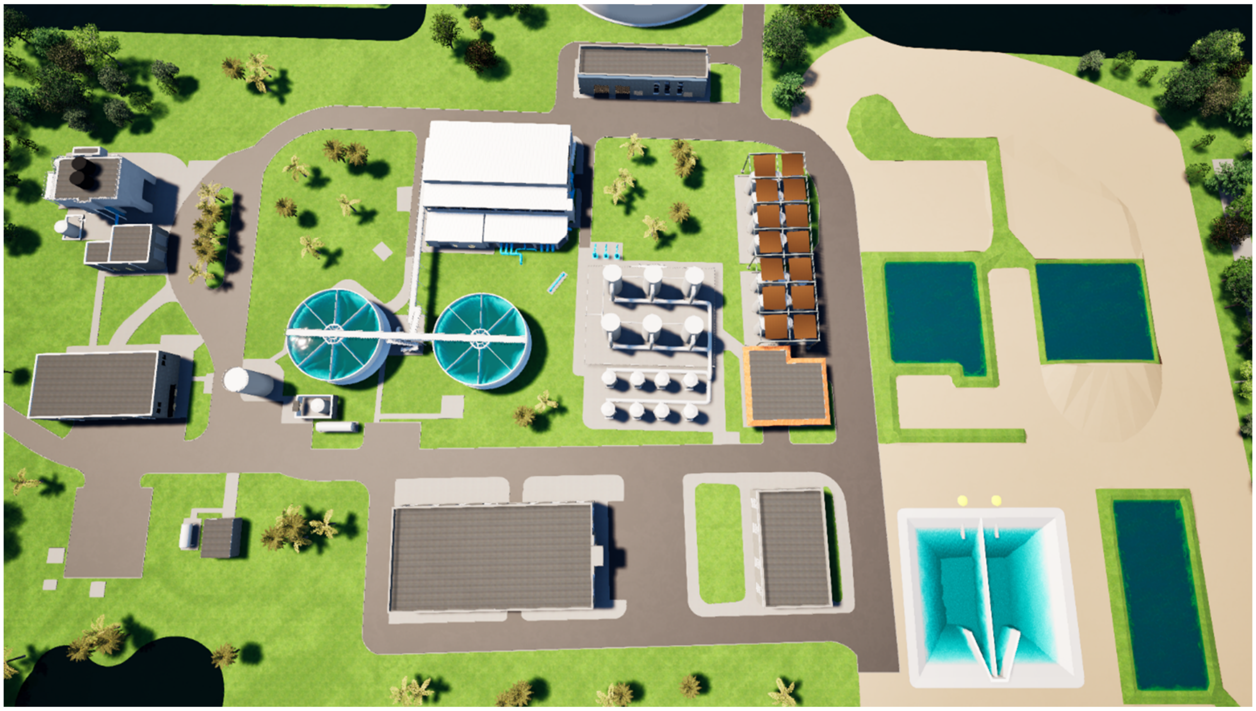

Figure C.114: PBC WTP 2 Overall Image 5 from "Best Practice" Workflow

Figure C.115: PBC WTP 2 Overall Image 6 from "Best Practice" Workflow

Figure C.116: PBC WTP 2 Overall Image 7 from "Best Practice" Workflow

Figure C.117: PBC WTP 2 Proposed Buildings Image from "Best Practice" Workflow

Figure C.118: PBC WTP 2 Generator Building Image from "Best Practice" Workflow

Figure C.119: PBC WTP 2 HSPS Image from "Best Practice" Workflow

Figure C.120: PBC WTP 2 HSPS Interior Image from "Best Practice" Workflow

Figure C.121: PBC WTP 2 Lime Softener Image from "Best Practice" Workflow

Figure C.122: PBC WTP 2 Nanofiltration Image from "Best Practice" Workflow

Figure C.123: PBC WTP 2 Nanofiltration Interior Image from "Best Practice" Workflow

Figure C.124: PBC WTP 2 OC Scrubbers and Degassifier Image from "Best Practice" Workflow

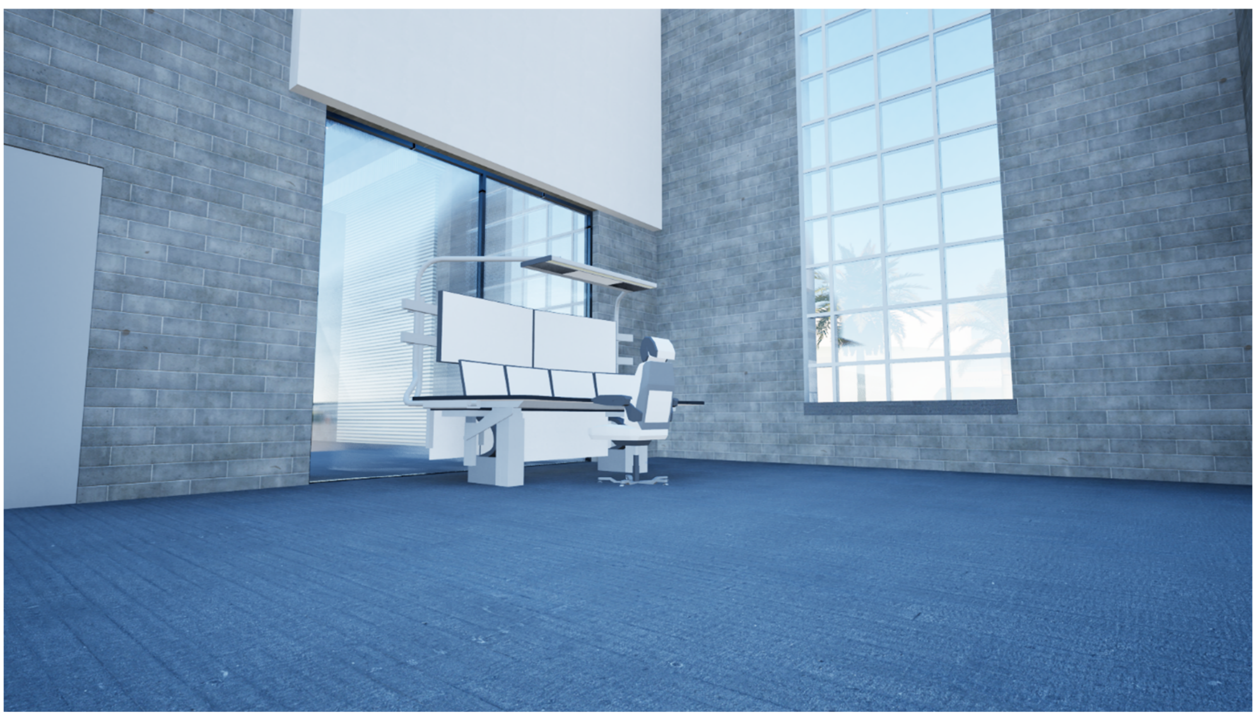

Figure C.125: PBC WTP 2 Operator Room Image from "Best Practice" Workflow

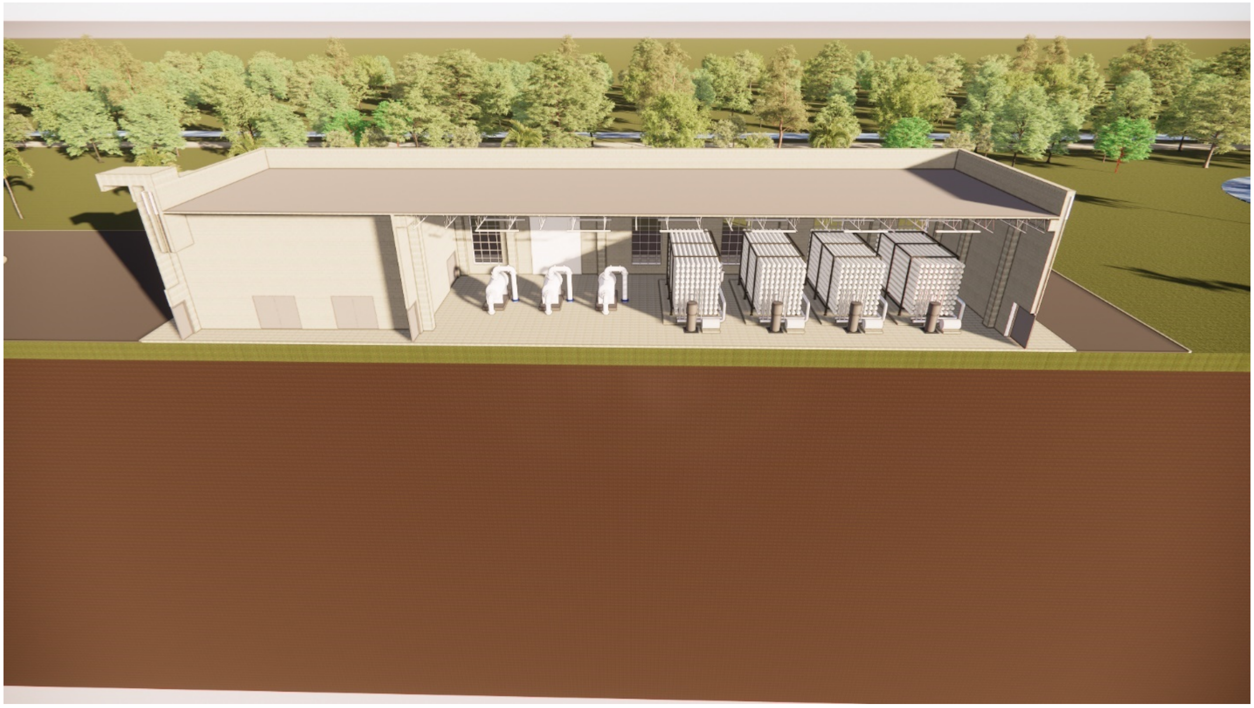

Figure C.126: PBC WTP 2 Section Image 1 from "Best Practice" Workflow

Figure C.127: PBC WTP 2 Section Image 2 from "Best Practice" Workflow

Figure C.128: PBC WTP 2 Video Deliverable from "Best Practice" Workflow

Figure C.129: PBC WTP 2 Image of Live Demonstration from "Best Practice" Workflow

Figure C.130: PBC WTP 2 Executable File from "Best Practice" Workflow

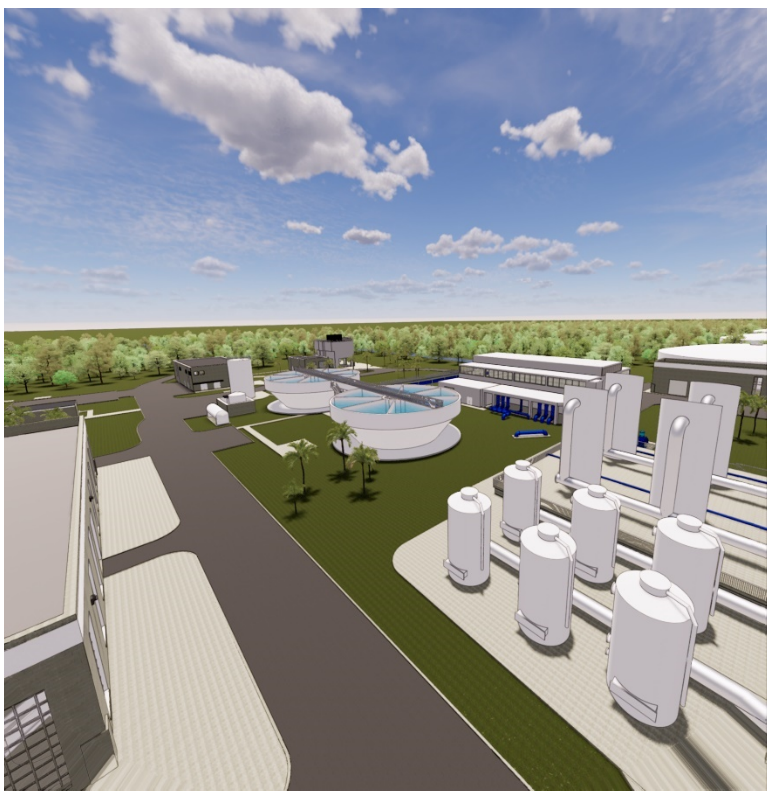

Figure C.131: PBC WTP 2 Image of VR Environment from "Best Practice" Workflow

Figure C.132: PBC WTP 2 AI Image of Generator Building from "Best Practice" Workflow

Figure C.133: PBC WTP 2 AI Image of HSPS from "Best Practice" Workflow

Figure C.134: PBC WTP 2 AI Image of Nanofiltration from "Best Practice" Workflow

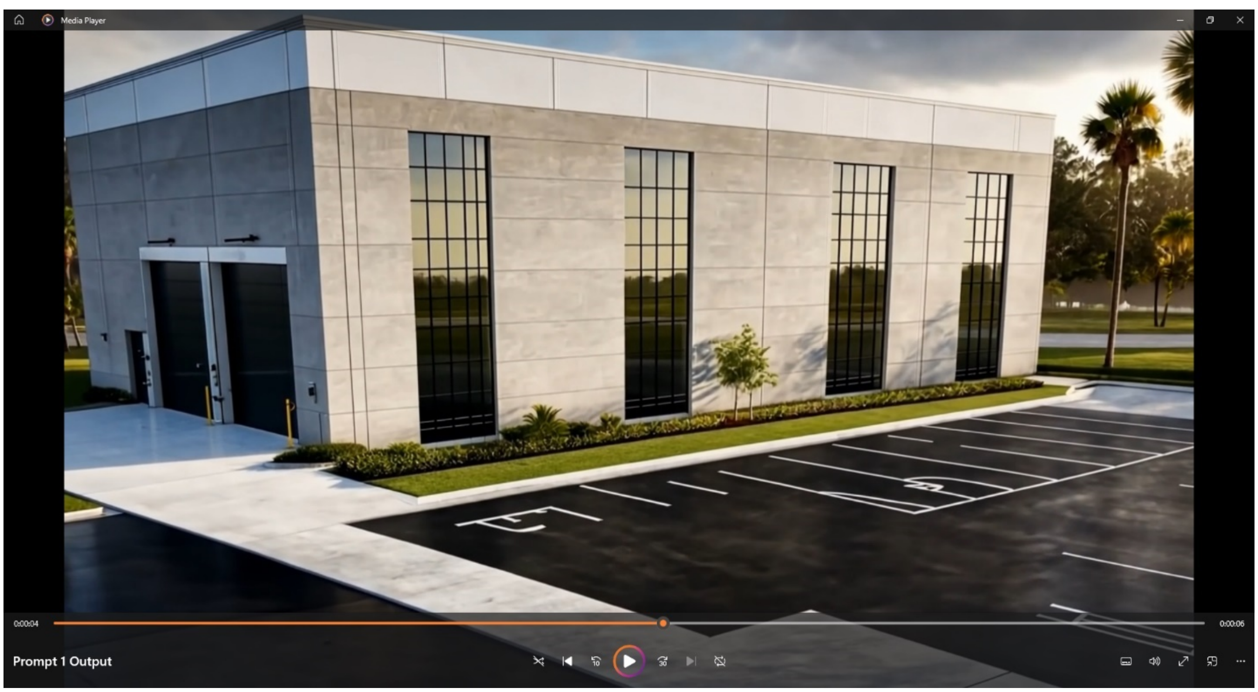

Figure C.135: PBC WTP 2 AI Video of Generator Building from "Best Practice" Workflow

Figure C.136: PBC WTP 2 AI Video of HSPS from "Best Practice" Workflow

Figure C.137: PBC WTP 2 AI Video of Nanofiltration from "Best Practice" Workflow

APPENDIX D: CH WTP GAC DELIVERABLE PACKAGE UTILIZING AVERAGE REQUIREMENTS

In order to provide readers with context regarding the visualization deliverable package developed for the Concord Hillgrove WTP GAC Upgrade project pursuit utilizing the proposed "best practice" workflow for average projects (outlined in table 3.2.7.1), the following pages contain images of each of the deliverables developed for this methodology of the Concord Hillgrove case study:

Figure D.138: Hillgrove WTP Overall Image 1 for "Best Practice" Process with Avg. Req.

Figure D.139:Hillgrove WTP Overall Image 2 for "Best Practice" Process with Avg. Req.

Figure D.140: Hillgrove WTP Overall Image 3 for "Best Practice" Process with Avg. Req.

Figure D.141: Hillgrove WTP Overall Image 4 for "Best Practice" Process with Avg. Req.

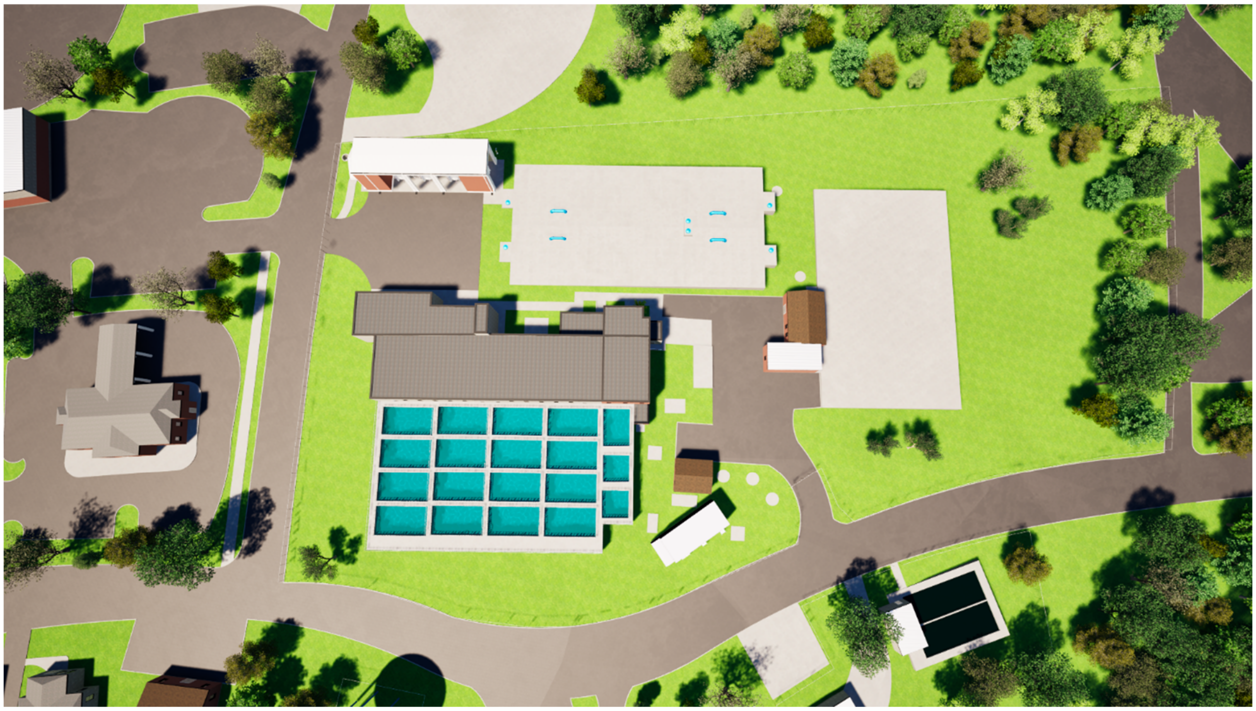

Figure D.142: Hillgrove WTP Overall Image 5 for "Best Practice" Process with Avg. Req.

Figure D.143: Hillgrove WTP Proposed Image 1 for "Best Practice" Process with Avg. Req.

Figure D.144: Hillgrove WTP Proposed Image 2 for "Best Practice" Process with Avg. Req.

Figure D.145: Hillgrove WTP Proposed Image 3 for "Best Practice" Process with Avg. Req.

Figure D.146: Hillgrove WTP Proposed Image 4 for "Best Practice" Process with Avg. Req.

Figure D.147: Hillgrove WTP Proposed Image 5 for "Best Practice" Process with Avg. Req.

Figure D.148: Hillgrove WTP Video for "Best Practice" Process with Avg. Req.

Figure D.149: Hillgrove WTP Executable File for "Best Practice" Process with Avg. Req.

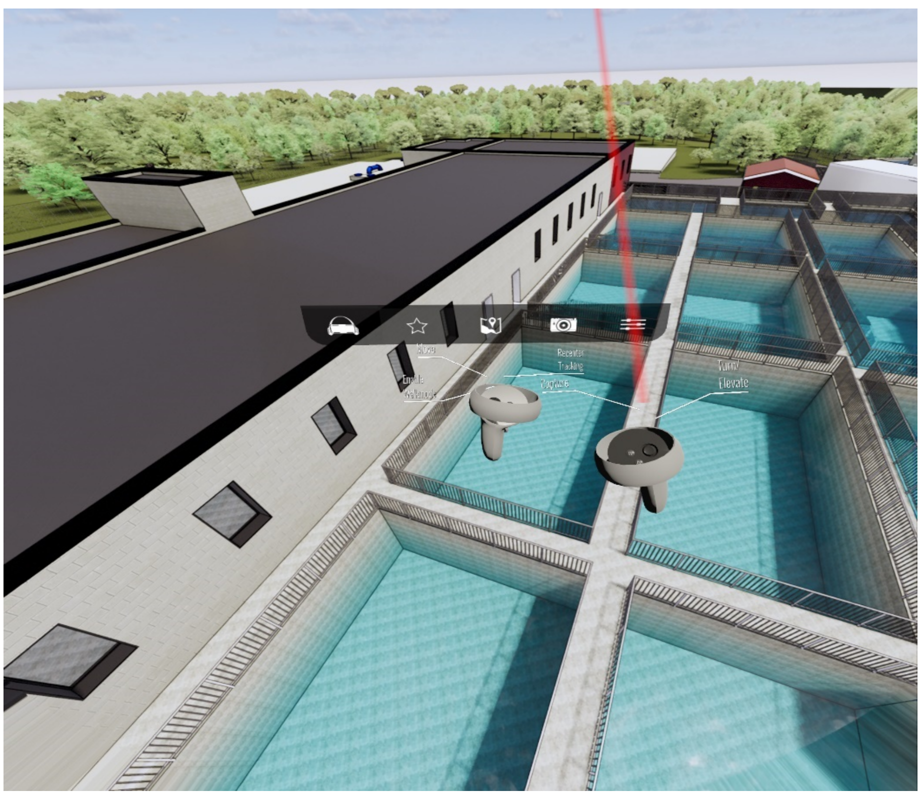

Figure D.150: Hillgrove WTP VR Environment for "Best Practice" Process with Avg. Req.

Figure D.151: Hillgrove WTP AI Image for "Best Practice" Process with Avg. Req.

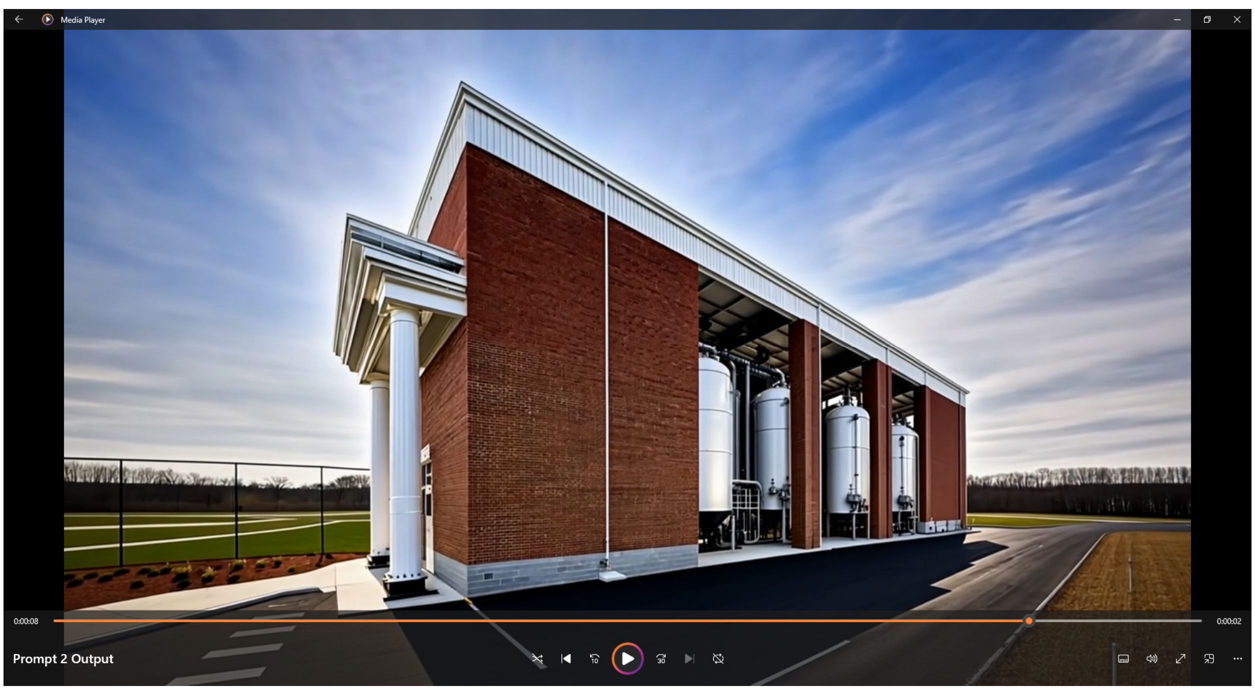

Figure D.152: Hillgrove WTP AI Video 1 for "Best Practice" Process with Avg. Req.

Figure D.153: Hillgrove WTP AI Video for "Best Practice" Process with Avg. Req.

APPENDIX E: CH WTP GAC DELIVERABLE PACKAGE UTILIZING DEMANDING REQUIREMENTS

In order to provide readers with context regarding the visualization deliverable package developed for the Concord Hillgrove WTP GAC Upgrade project pursuit utilizing the proposed “best practice” workflow for demanding projects (outlined in table 3.2.7.2), the following pages contain images of each of the deliverables developed for this methodology of the Concord Hillgrove case study:

Figure E.154: Hillgrove WTP AI Image from “Best Practice” Process for Demanding Projects

Figure E.155: Hillgrove WTP AI Video from "Best Practice" Process for Demanding Projects

Figure E.156: Hillgrove WTP Live Demo from "Best Practice" Process for Demanding Projects