Monteverde Environmental Technology Park
Monteverde, Costa Rica

A Major Qualifying Project
Submitted to the faculty of
Worcester Polytechnic Institute
In partial fulfillment of the requirements
for the degree of Bachelor of Science

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Justin Welch

In collaboration with:

Abstract

The goal of this project was to create a design for a waste treatment facility site in Monteverde, Costa Rica. To create a 2D site design the team collaborated on Bluebeam Revu. Together, the team then began a 3D design using AutoCAD Civil 3D for site grading and Revit for 3D renderings of the site components and walkthroughs. Once the design was complete the team presented the findings to the ASADA, the local Environmental Management Program in Monteverde and sponsor for this project.

Executive Summary

The goal for this MQP was to fulfill WPI's engineering requirements by designing an overall site plan, earthwork design, and a 3D visual supplement for an Environmental Technology Park (PTAM) in Monteverde, Costa Rica. To accomplish this goal the team laid out three main objectives:

1. Characterize the project site.
2. Condition the project site.
3. Develop true to scale 3D renderings, grading optimization, and walk-through of the project site.

The team first characterized the site by collecting data including photos, topographic data, existing landmarks, and property boundaries. This was gathered in various ways from drone flights, Google Earth, site visits, and research on existing databases. The data was then discussed with the our contact from the ASADA, Justin Welch, to solidify the team's understanding of the work required to condition the site.

Then came the 2D site design utilizing Bluebeam Revu. The design went through a comprehensive, iterative process between Justin Welch, the Municipality, and the team until a finalized 2D site design was agreed upon. To accomplish this goal true-to-scale features were created in Bluebeam to represent buildings, trucks, and roads.

Once the 2D site was complete, the 3D design began. DroneDeploy was used to collect topographic data of the site and was then transferred into AutoCAD as contour lines. These lines were then combined into a continuous surface data to resemble the existing ground conditions. A grading optimization was conducted within the software to understand the quantities of earthwork and constructability. The final build plot, terrace, and road elevations were then embedded onto the existing ground surface. As the grading process was conducted in Civil 3D, the site component buildings were built and furnished in Revit. The final results of these processes were scaled building renderings, a 3D earthwork model with quantity takeoff, and a virtual walkthrough of the site components

Capstone Design Statement

The team was tasked with the characterization, design, and visual modeling of a site development in Monteverde, Costa Rica as part of a preliminary construction process. The Environmental Management Program of the ASADA (Administrative Association for Sewers and Aqueducts), the local water authority, chose and acquired a rural site location for their Monteverde Environmental Technology Park (PTAM). The PTAM will be the common grounds for a waste transfer center, productive treatment plant, and a wastewater treatment facility. The goal of this unified site is to promote synergy between waste management fields as they consolidate solid waste more efficiently, garner resources from organic waste, and take both active and preventative measures to treat wastewater in Monteverde. The PTAM will also promote political unity and save money as Monteverde works towards their goal of being a zero-waste community.

The main goal for this MQP was to first characterize the site to create a working foundation of data. Then, the team created a 2D site design that optimized the functionality of the desired components while adhering to all legal and physical constraints. Finally, a 3D visual model of the site components was created to help convey the future of the site to individuals of all backgrounds and professions. The final deliverables were a 2D site plan that highlights the relationship between the site components and their locations, a 3D earthwork model showcasing the conditioning of the existing terrain for construction, and a 3D architectural site model with a walkthrough showcase of the site renderings.

According to the Accreditation Board for Engineering and Technology (ABET), a nonprofit, non-government organization that sets accreditation standards for specific degrees and program levels, engineering students must incorporate consideration for realistic project constraints. The main constraints for this project were economic, ethical, environmental health and safety, political, and constructability and sustainability.

Economic:

As with all projects there were economic constraints that needed to be taken into account. The ASADA had a limited budget and a strong reliance on municipal funding. Therefore, designing a site that would be within budget while still meeting the sponsor's and municipality's goals for the site was a critical aspect of this project.

Environmental Health and Safety:

The environmental impact of the site was also considered because it includes a wastewater management component, and an improper design could lead to detrimental environmental and safety impacts in the surrounding community. Improper grading of the site may lead to flooding and landslides. Construction causes noise pollution for the neighbors and increased traffic to the site. Also, the wastewater treatment plant and productive treatment was placed downwind of the site where there are no neighbors and trees line the property to keep the odors in. The team minimized all the environmental impact as much as possible.

Political:

Coordination with the municipal government in Monteverde was required in this project as they are the main stakeholders involved in funding the PTAM. The ASADA had broken the project into phases with the first phase focused on conditioning the site, the second phase focused on building the site components, including the transfer center, productive treatment plant, and wastewater treatment plant so that the municipal government can realize the midterm benefit before continuing funding the project. This project focused on working with ASADA to help the municipal government realize the full potential of the PTAM.

Constructability & Sustainability:

Furthermore, the materials chosen would be readily available and meet the needs of the sponsor. Constructability and sustainability are related because construction methods should be able to be implemented and must consider impacts to the natural environment, the built environment, and all its inhabitants

Professional Licensure Statement

Earning a Professional Engineering (PE) Licensure is a great achievement. It shows employers and clients that one is not only prepared, but well qualified to take on higher level tasks. A PE signifies the readiness to combine specialized skills with a high standard for ethics, professionalism, and quality of work to complete a project. An engineer with a PE is different from an engineer who did not earn their PE because of a professional engineer's ability to prepare, sign, seal, and submit engineering plans for public approval and for clients. An individual must complete the following to become a licensed Professional Engineer:

- Receive a four-year degree from an ABET-accredited engineering program
- Pass the Fundamentals of Engineering (FE) exam to become an Engineer in Training (EIT)
- Complete four years of progressive engineering experience under the direction of a PE
- Pass the Principles and Practices of Engineering (PE) exam.

Acknowledgements

The team would first like to thank Justin Welch and the ASADA for all the time he spent helping the team complete this project. The team would also like to thank both of the Civil and Environmental Engineering advisors, Professor Mingjiang Tao and Professor Suzanne LePage. Lastly, the team would like to extend their thanks to the community of Monteverde for being so welcoming during their stay.

Authorship

This Major Qualifying Project (MQP) was completed by Civil Engineering Undergraduate Students from Worcester Polytechnic Institute (WPI). All members of the team were responsible for writing, reading, and editing the paper. The creation of the 2D site design was a collaborative step that everyone contributed to equally. Colby Jensen took the lead on learning how to edit and grade topographic data in AutoCAD; he was responsible for this portion of the 3D design. Rhys Kalama and Skylah Mahon worked simultaneously on designing the site components themselves and creating 3D renderings and walkthroughs using Revit to accurately depict what the buildings could look like when completed. Feedback was provided by Professors Mingjiang Tao and Suzanne LePage

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1. Introduction

Due to the presence of the Cloud Forest Reserve and many other beautiful natural attractions like the unique rainforest wildlife, tourists flock to Monteverde in mass. Tourism is so prevalent, in fact, that it comprises one of the largest economic sectors and makes Monteverde the 3rd most visited destination in Costa Rica (Brinkhoff, 2020). While bringing many economic benefits and new development to the area, the floating population of well over 150,000 people poses a host of issues for Monteverde's full-time population of roughly 4,800 (Brinkhoff, 2020). Monteverde is currently facing a crisis of improper disposal and sanitation of their sewage and solid waste. The main town of Santa Elena can be seen in Figure 1.1 below.

Figure 1.1. Main town of Santa Elena (N/A, 2021).

Monteverde is a municipal district located in the Puntarenas province of Costa Rica in the Cordillera de Tilarán mountain range at the top of the region's watersheds, causing it to have a direct influence on the surrounding environment and populations. This is where the ASADA, the local Environmental Management Program in Monteverde, plans to implement the "Monteverde Environmental Technology Park" in conjunction with the Municipal Council to address numerous aspects of this socio-economic waste problem. The three main components of the site will be the waste transfer center, productive treatment plant, and wastewater treatment facility. This development will be a common site for more political unity, promote synergy between waste management fields, and save money as the Monteverde community works towards the goal of being a zero-waste system (Welch, 2021).The goal for the MQP is to design an overall 2D site plan, earthwork design, and a 3D visual supplement for an Environmental Technology Park in Monteverde. The ASADA can then use this project as a tool to convey the functionality and short to mid-term benefit of the site as they work to receive more traction and funding within the Municipality. To accomplish this goal the team laid out three main objectives:

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2. Background

Costa Rica is a land of contrasts; banana plantations, flaming volcanoes, misty black sand beaches, and a thriving modern capitalist economy. A remarkably stable country, both politically and economically, Costa Rica offers an opportunity to become immersed in a Central American culture where democracy, economic development, and concern for the environment are a permanent part of the landscape. Monteverde was initially settled by American Quakers in the 1950s who purchased the land from local homesteaders and set up a small community of dairy farms. It has since become a major conservation and research hub due to its protected ecosystems and rich biodiversity (Desafio, 2021). The region currently hosts the largest network of private reserves of land conservations in Central America making the region's waste problem increasingly urgent.

2.1. Monteverde Waste Problem

In addition to the need for environmental and forest protection, Monteverde's current waste problem generates risks for public health, economic costs both at the individual level and at the community level and contributes to climate change through increased greenhouse gas emissions (Welch, 2021). As a result of the increased demand for urban development, there has been a consequential lapse in construction standards producing high levels of untreated greywater in the community. In addition, 98% of homes and businesses use septic systems as the main form of blackwater treatment and 66% of the septic sludge pumped is not adequately treated (Welch, 2021). This is due to an excessive strain on the waste management system where septic trucks have long inefficient routes and unregulated dumping is the unfortunate side effect. This matter is extremely pressing as rivers/streams in the distract have already shown contamination. If wastewater sanitation measures are not put into practice from both a prevention and treatment, there will be no clean water sources left for future urban communities. The map of Monteverde's rivers and their contamination levels can be seen below in Figure 2.1. The highly polluted and poor water quality are directly correlated with the current urbanization in the main town of Santa Elena and displayed as yellow and orange river lines. As urbanization increases as projected, the current clean water sources will be largely at risk.

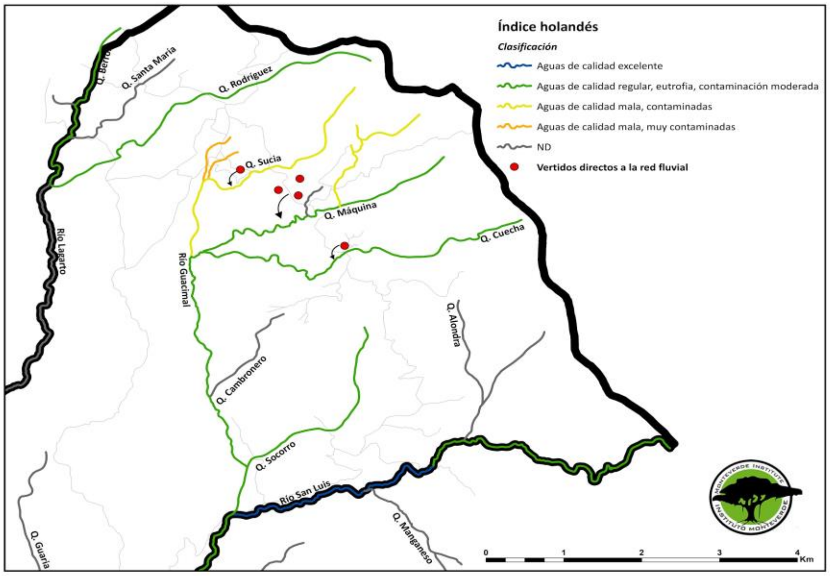

Figure 2.1. Pollution levels of rivers and streams in Monteverde (MVI, 2021).

Solid waste is another aspect of Monteverde's waste management problem that needs to be addressed. In the current system, solids that go to landfills are losing significant efficiency in the compacting and transport routes of trucks that must drive many kilometers daily. The sorting of solids also poses an issue as the recycling centers are extremely limited on space (seen in Figure 2.2), and organic waste potential in terms of nutrients and energy is left unrealized.

Figure 2.2. Monteverde recycling facility (Welch, 2021).

However, the need for proper management of waste has not gone unnoticed by the Municipality and the ASADA del Distrito Monteverde. Their vision is one of a future free of contamination and full of opportunities to recover resources such as energy, nutrients, raw materials, and water for reuse. This future exists in a system that realizes a mutually beneficial relationship between urban and rural areas (Welch 2021).

2.2. Sponsor Background

The sponsor for this project is Justin Welch who is the supervisor for the Environmental Management Program at ASADA del Distrito Monteverde, Costa Rica. It is an Association that provides, regulates, and guarantees the service of drinking water to communities in Monteverde (ASADA, 2021). ASADA knows that to enact a permanent and positive change, they must motivate the community to practice conservation and instill cultural values associated with the protection of clean water. To accomplish this, their mission is to apply an appropriate maintenance of the system, where the quality, quantity and continuity of the service is guaranteed at a fair cost. ASADA must be community leaders in the Monteverde District as the projection of their work protecting aquifers and treating wastewater will be critical in providing safe drinking water for the future generations to come.

Figure 2.3. ASADA washed and painted springs for "World Water Day (ASADA, 2021).

The community of Santa Elena initially started with a supply of water from an artisan aqueduct that was in service for 30 years. In 1980, the first Aqueduct Administrator Committee was organized and only a few years later the water systems of Cerro Plano, Santa Elena, and Cañitas were united. Many years later in 1998 is when the ASADA known today was created to improve the water system. They started with the installation of a water disinfection system making it one of the first aqueducts with such high drinking quality. In 2008, due to the rise in tourism, expensive work began on the water system under ASADA's supervision. In 2011, in conjunction with their governing body AyA, the project known by the community as kfw was created. By 2015 the project was complete, achieving a practically new Aqueduct, and with greater water supply capacity and sanitation standards. After completion this aqueduct was awarded 7 Stars in the Sanitary Quality Seal Program of the National Water Laboratory of the Costa Rican Institute of Aqueducts and Sewers (AyA), placing it as one of the best Aqueducts in the country (ASADA, 2021).

Today, the ASADA use their environmental and water conservation experience to forge the path towards a cleaner Monteverde. Their newest project, in collaboration with the Municipal authority, is a site development called the "Monteverde Environmental Technology Park" (PTAM) that integrates sanitation projects related to solid waste and wastewater. This multifaceted project plans to address many of the previously outlined environmental and public health crises that Monteverde currently faces and will grow alongside the developing community.

2.3. Environmental Technology Park

ASADA's mission in creating an Environmental Technology Park is to promote the ideal, productive, and innovative management of solid waste, liquids, and gasses for the Monteverde region. They seek to generate greater efficiencies in the development and provision of sanitation systems, maximize the transformation of waste into resources, and incubate new green ventures through Public-Private Alliances that link actors, infrastructure, services, and programs (Welch, 2021). This will act in such a way that Monteverde efficiently achieves local, national, and global goals in improving environmental health, human development, sectoral decarbonization, adaptation to climate change, and bioeconomy.

Figure 2.4. Transfer center example (Welch, 2021).

The PTAM was created considering a multitude of factors with related public policies at the national level and municipal strategic plans regarding wastewater, solid waste and climate. In addition, the current low recovery rate of recoverable waste and the lack of community infrastructure for wastewater treatment made apparent the need to take advantage of new technological offers. The PTAM boasts ambitious goals but with a practical design it will allow the community to recover and transform a greater amount of solid waste, promote new mid-term ventures, and treat water for long-term reuse. Other considerable benefits of the combined site are the shared/reduced development costs, joint management/operation, and minimized environmental impact. (Welch, 2021). According to data from The Commission for Resiliency to Climate Change in Monteverde (CORCLIMA), Monteverde is projected to produce almost 50% more waste by 2045 (Figure 2.5) due to increased tourism and population growth (Welch, 2021).

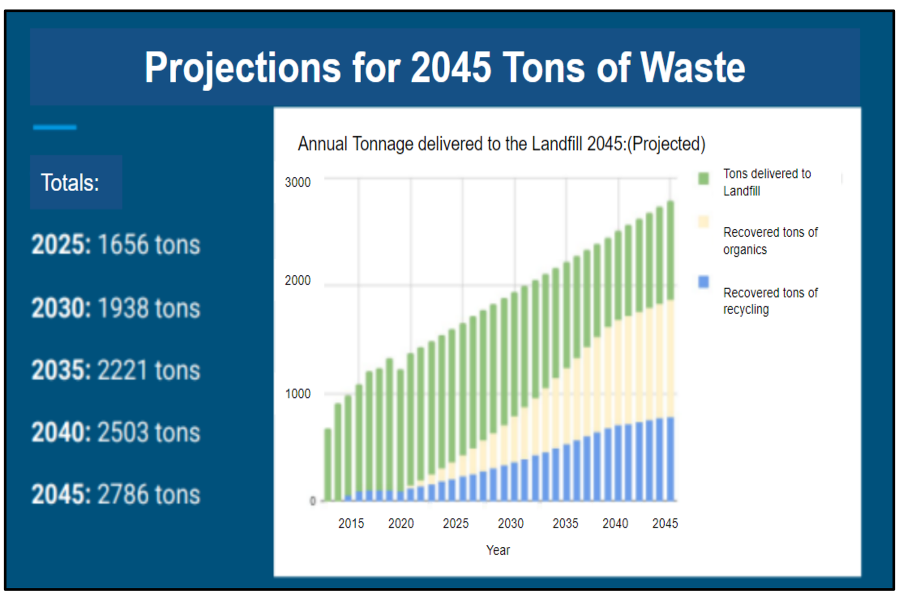

Figure 2.5. Monteverde projected waste production (Welch, 2021).

In face of growth trends and current inefficiencies, the PTAM will address problems in the transportation of non-recoverables (i.e., transfer trailers using tipping floors), breaking-up value chain for recyclables and creating greater economies of scale in terms of overall recovery and transportation costs (i.e., the direct storage of processed recyclables in trailers), the management of new, separate waste streams via the public drop-off area, and an on-site transformation of organics (both solid and liquid) at the productive treatment plant. Despite organics and recyclables representing 70% of the overall annual tonnage, only a small fraction of recyclables was being recovered. Additionally, no formal program existed for organics prior to 2020 (Welch, 2021). Figure 2.6 below shows the solid waste breakdown.

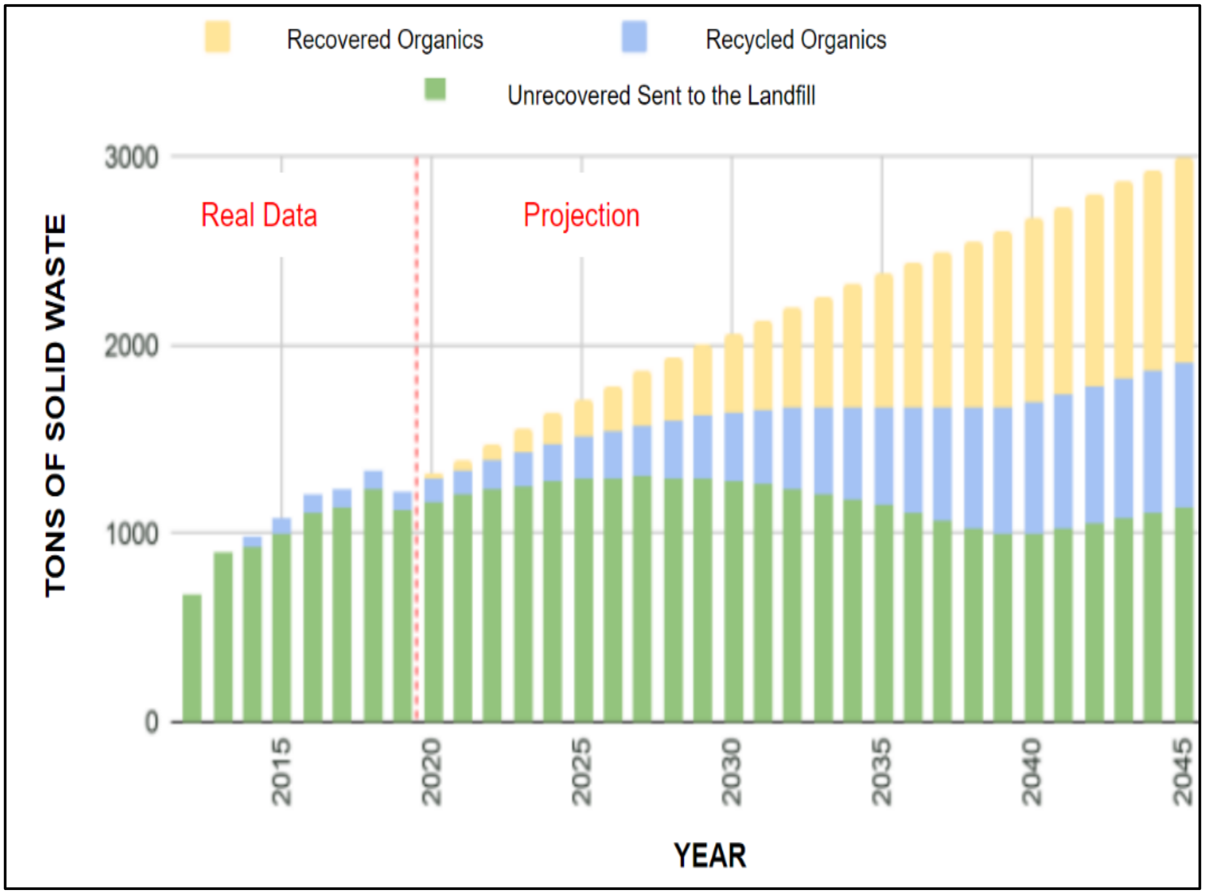

Figure 2.6. Monteverde solid waste production (Welch, 2021).

The three main components of the PTAM are the transfer center (CDT), the productive treatment plant (PTP), and wastewater treatment system (PTAR) seen in Figure 2.7. The auxiliary components include the public drop-off, weigh station, offices, classrooms, administrative buildings, laboratories, and workshop.

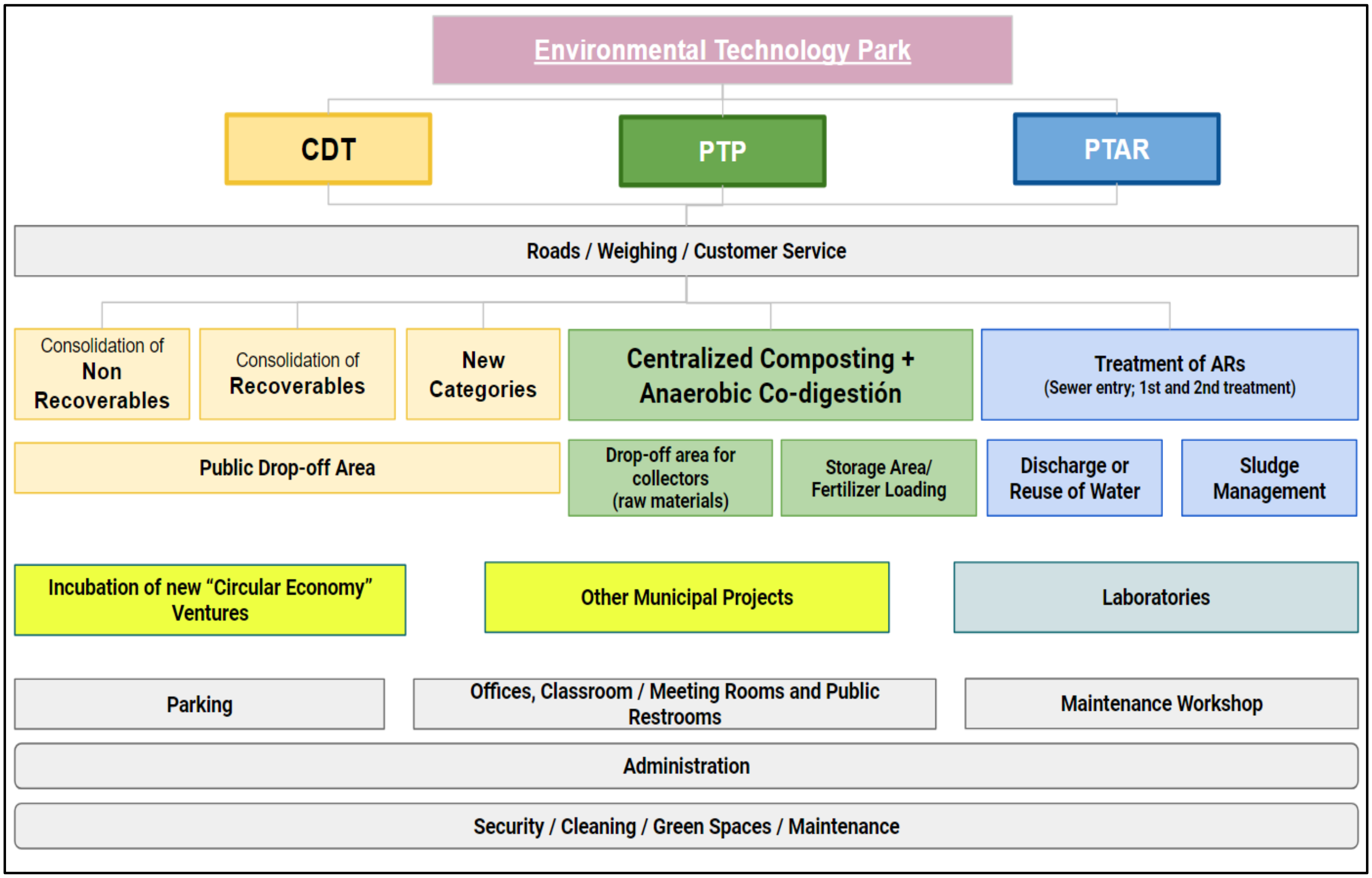

Figure 2.7. Environmental Technology Park components (Welch, 2021).

The goal of the transfer center is to promote new consolidation strategies of recoverable and non-recoverable waste by facilitating efficient intermodal transfers and measurements and providing new services and forms of waste management (ex. Construction debris, refrigerants, etc.). It would modify the existing operations towards a third-party transfer and minimize local processing of cardboard, plastic, aluminum, and paper. This in turn would save 9 business days of work and create new collection routes in neighborhoods. (Welch, 2021) The transfer center will have the ability to be implemented in the short term and develop in stages which offers strong value for the Municipality. It will also allow for the inherent involvement of other initiatives with hopes to form long term alliances as the PTAM shapes the flow of waste in Monteverde.

The next component of the PTAM is the productive treatment plant. The main objectives are to integrate technologies that generate co-benefits for multiple sectors and to transform organic waste into energy, nutrients, and water. The current process consists of organic waste that is gathered from the community and put into aerated static pile compost reactors. These use a series of flow pipes that run into the compost piles and provide oxygen to the inside which eliminates the need for manual turning of the piles and its associated labor costs. To supplement this aspect of the PTAM, there is also work being done to create an anaerobic co-digestion reactor with a batch stir tank. This reactor would take in a mixture of organic waste flows, of which the biggest concern is septic sludge and fat, oils, and grease (FOG). Septic sludge and FOG are a big concern for Monteverde because the current trajectory of urban development means greater amounts of waste, and these cannot be sent to a typical wastewater treatment facility. This is because FOG is not soluble and has a molecular structure that requires exponentially more resources like time and energy to breakdown through a typical wastewater treatment train. Fortunately, the anaerobic co-digestion reactor will optimize composition, treatment services, and production of biogas by mixing the septic sludge and FOG with ground up food waste and dairy whey from the abundance of dairy farms in the area. Another positive output from the reactor would be liquid digestate that can inoculate new compost batches and help treat pathogens coming out of the septic sludge through the solid's matrix.

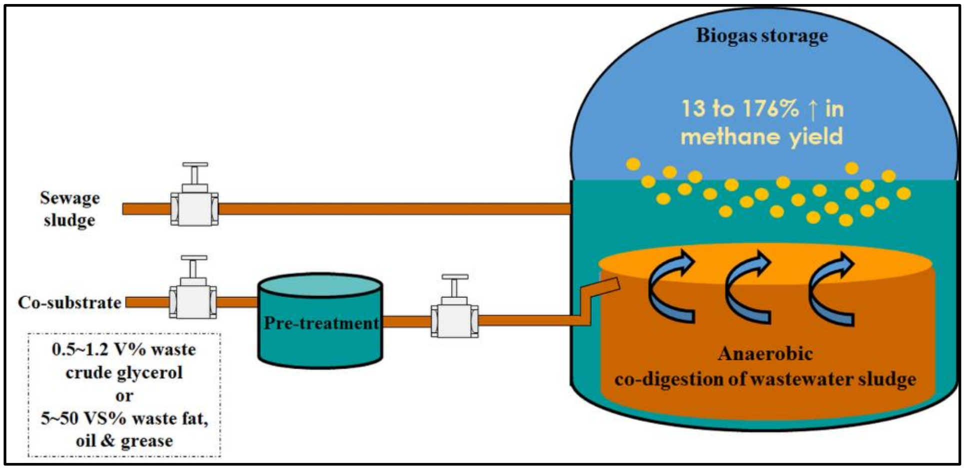

Figure 2.8. Anaerobic Co-Digestion Reactor Concept (Chow, 2020).

The final main component of the PTAM is the wastewater treatment system. One objective for this system is to provide a sewage collection and treatment solution within the area for both gray water and black water. Ideally this will service the highest number of homes and businesses possible and operate at low costs. Another objective for the wastewater treatment system is improving the water quality in Monteverde's most affected basins and preventing future contamination. This will work to ensure the public health and socio-economic well-being of local communities as Monteverde continues to be an increasingly popular tourist destination. National Technical University in Costa Rica is currently working on a comparison study of different configurations for the wastewater treatment train. This will produce a workable knowledge of space necessary on-site, flow into the facility, and operating efficiencies. In Figure 2.9 below, the anticipated results of the PTAM can be seen for years to come.

Anticipated results:

Concept	Profits Goals	
Environmental	Greater recovery of recoverable solid waste	+ 358% by 2026
	Better wastewater sanitation	1,888 m^3 treated / day to 2030
	Organic sludge transformed into resources for local use	By 2025, min. 239 m^3/ year transformed to biosolids
	Collection / storage of refrigerant gasses	50% by 2030
	GHG emission reduction potential	1,667.23 tons CO_{2-e}/year
Partner economic	Better low-cost sanitation services for:	6,500 local inhabitants 150,000 annual visitors 300 local businesses
	Organic inputs made available to local producers	At least 50 coffee, milk and vegetable farmers

Figure 2.9. Predicted benefits of the Environmental Technology Park (Welch, 2021).

2.4. Site Planning Process

As seen in Figure 2.10, there are 9 categories of steps that go into site planning: engaging stakeholders, site analysis, programming, site design, site engineering, landscape design, financial planning, impact analysis, and construction management. The steps in these categories are then put into 4 phases: preliminary, schematic, refinement, and documentation (Hack, 2018). The scope of this MQP falls under preliminary, schematic, and some refinement. The process of engaging stakeholders includes the identification of clients, public engagement, public approval, and entitlements. These steps are for communicating with those requesting the project to determine exactly what is wanted before introducing the idea to the public. If the public approves, then the legal process begins to receive entitlements that grant rights for construction on proposed property lines.

Site analysis includes two main steps: initial site analysis and detailed site analysis. Initial site analysis is the composition of photos, aerial plans, maps, data, and results from a site visit. Detailed site surveying is similar, but as the name implies is created with many more factors in mind; specifics include topography, water sources, soil borings, and specific site features (Hack, 2018).

Programming can begin after site analysis. The first step is a sketch program where different site scenarios are considered; number and size of buildings, expected site performance, future innovations, etc. This allows new concepts to be introduced and manipulated. Working site program, market test of program, and final site program are the other steps in programming. Working site program recognizes uses for the site, standards to be met and used, and a timeline. A market test of the program may be requested, which judges refined financial pro forma reasonability. A final site program is created last, which reflects any changes agreed upon in the entitlements.

The next category is site design. A feasibility study comes first to determine if the plan is realistic. If determined feasible, schematic design can begin. Some information needed for this step should have been acquired in the first steps of engaging stakeholders, site analysis, and programming. Using the stakeholders wants, site analysis, and a sketch program, a detailed schematic can begin using all factors as considerations. A detailed site plan would follow this. To complete this step, a deep understanding of the end vision needs to be discussed between the client and site designer. It provides a guide for the entire project to influence main decisions. In general, a detailed site plan is like a schematic, but much more precise. A detailed plan includes a parcel plan and development guidelines. Then comes preliminary subdivision plans and a grading plan.

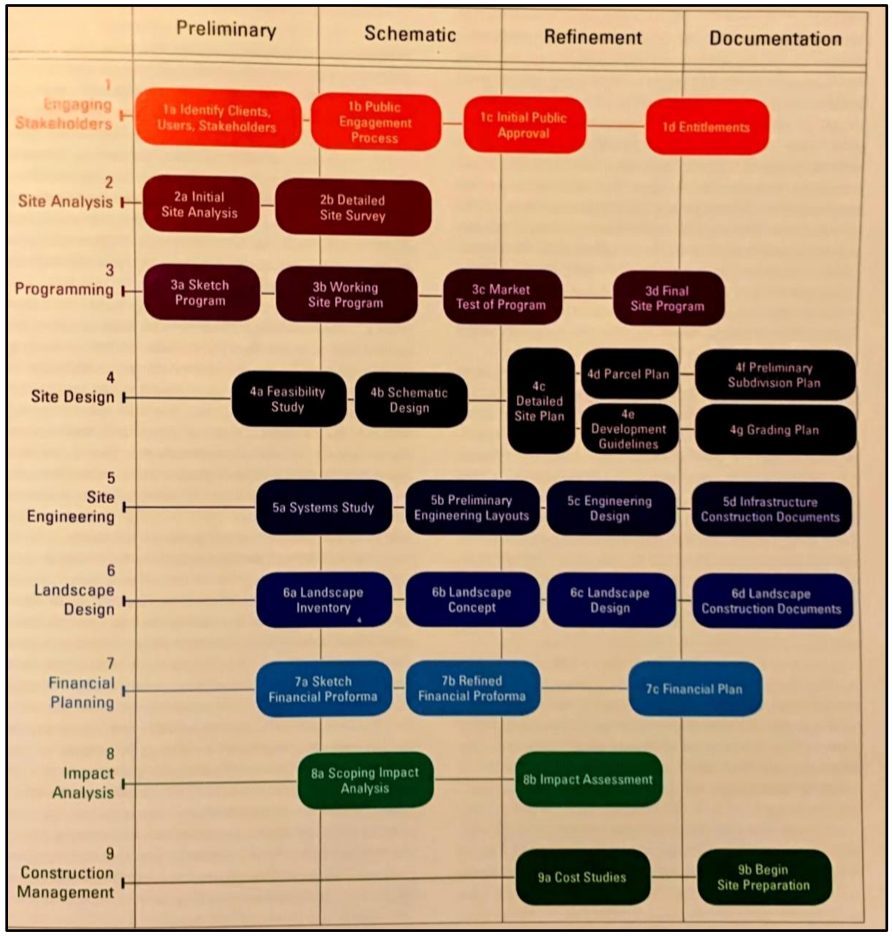

Figure 2.10. Site Planning process (Hack, 2018).

Category 6 is focused on landscape design. This begins with landscape inventory. A landscape concept is then created before landscape design. Like a plan schematic and a detailed site plan, a landscape design takes the main ideas from the landscape concept with many additional details. Lastly, there are landscaping documents that need to be prepared.

The next two categories are financial planning and impact analysis. Financial planning includes sketch financial pro forma, refined financial pro forma, and a financial plan. The financial proforma is necessary to determine which portions of the project should be cut. This then creates a refined financial pro forma that is reviewed in the programming category. The financial plan will reflect all changes made in the entitlement process. Impact analysis includes a scoping analysis and an impact assessment. A scoping of the impact analysis can begin alongside the creation of the schematic. This step takes measurements such as runoff into account for aid in placement of structures. An environmental impact assessment is also needed prior to gaining public approval. The assessment will dictate what needs to be adjusted, removed, or if the project can be completed at all. In a community such as Monteverde, where nature and environment are a large part of their appeal, this is a very important consideration.

The final category, construction management, has steps only in the refinement and documentation phase. First a cost study is done, followed by site preparation. Site preparation includes any task that must be completed before development of site (i.e., removal of existing structures).

2.5. Earthwork Design

Earthwork design is the process of using geotechnical data and soil reports to create a functional excavation plan for construction. This excavation plan brings the site from its existing topography to a proposed final grade that is suitable for the needs of buildings being developed. This is one of the earliest stages of the construction process and helps lay the foundation necessary to build. The process starts with subsurface investigations, such as borings or test pits, that help understand the quantities and structural properties of the workable soil present on site. This geotechnical data, combined with topographic data, can be used in computer software to create a model of earthwork necessary to achieve construction readiness. As seen in Figure 2.11, the proposed grades are modeled in a 3D space and shown in relation to their elevation levels.

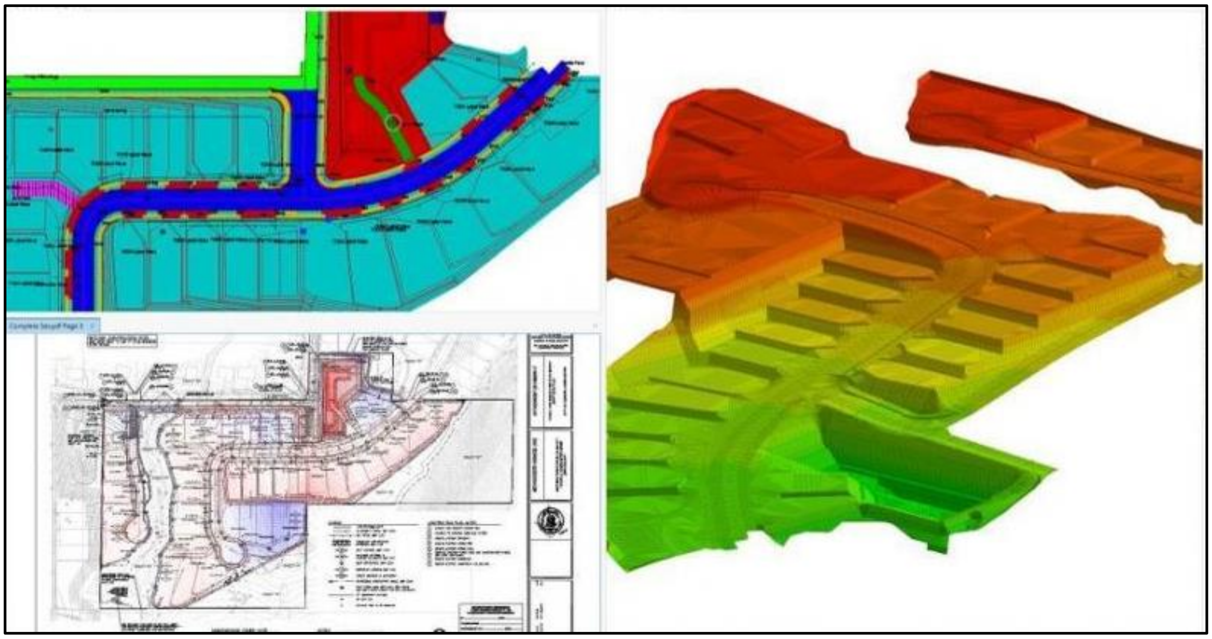

Figure 2.11. Earthwork Model displaying proposed grades (Clyde, 2021).

The reason it is so useful to create a model of the earthwork is because it can be used to calculate the exact cuts and fills for a project before excavation begins. Ideally, a site can be created from the proposed grades where there is balance between cuts and fills and it is not necessary to import or export soil.

3. Methodology

The site planning process for the Environmental Technology Park (PTAM) in Figure 2.10 includes all the steps necessary for the completion of this project. However, at the stage the team joined, not every step needed to be taken. The first step of stakeholder engagement had already been done and agreed upon by the ASADA and Municipality. The site's location was also selected prior to the start of the project. The first step conducted by the team was an analysis of the selected site.

The selected site is isolated from the surrounding community but close enough in proximity to service the Monteverde infrastructure. It also has the required features for the wastewater treatment facility (a gravity fed system) and previous designation of pastureland. In partnership with the Municipal Council, the ASADA has acquired a large plot of land (approximately 8 acres) and are now working towards receiving more funding and support to move forward with phases 1 and 2 of development. Phase 1 is the conditioning of the site to support all future development and phase 2 is the construction of the site components including the transfer center, productive treatment plant, and wastewater treatment plant. This is where the WPI team seeks to provide value to the ASADA.

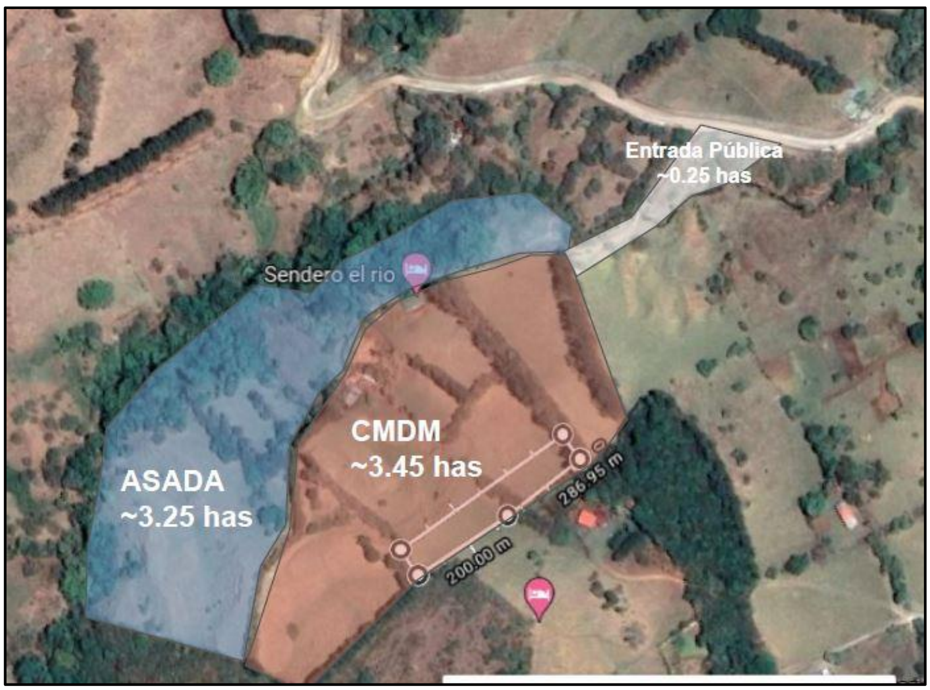

Figure 3.1. Purchased Site for the Environmental Technology Park (Welch 2021).

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To better convey the complexity of the iterative process used in this project the team created a flowchart detailing the steps used in the methodology and how it led to the results (Figure 3.2).

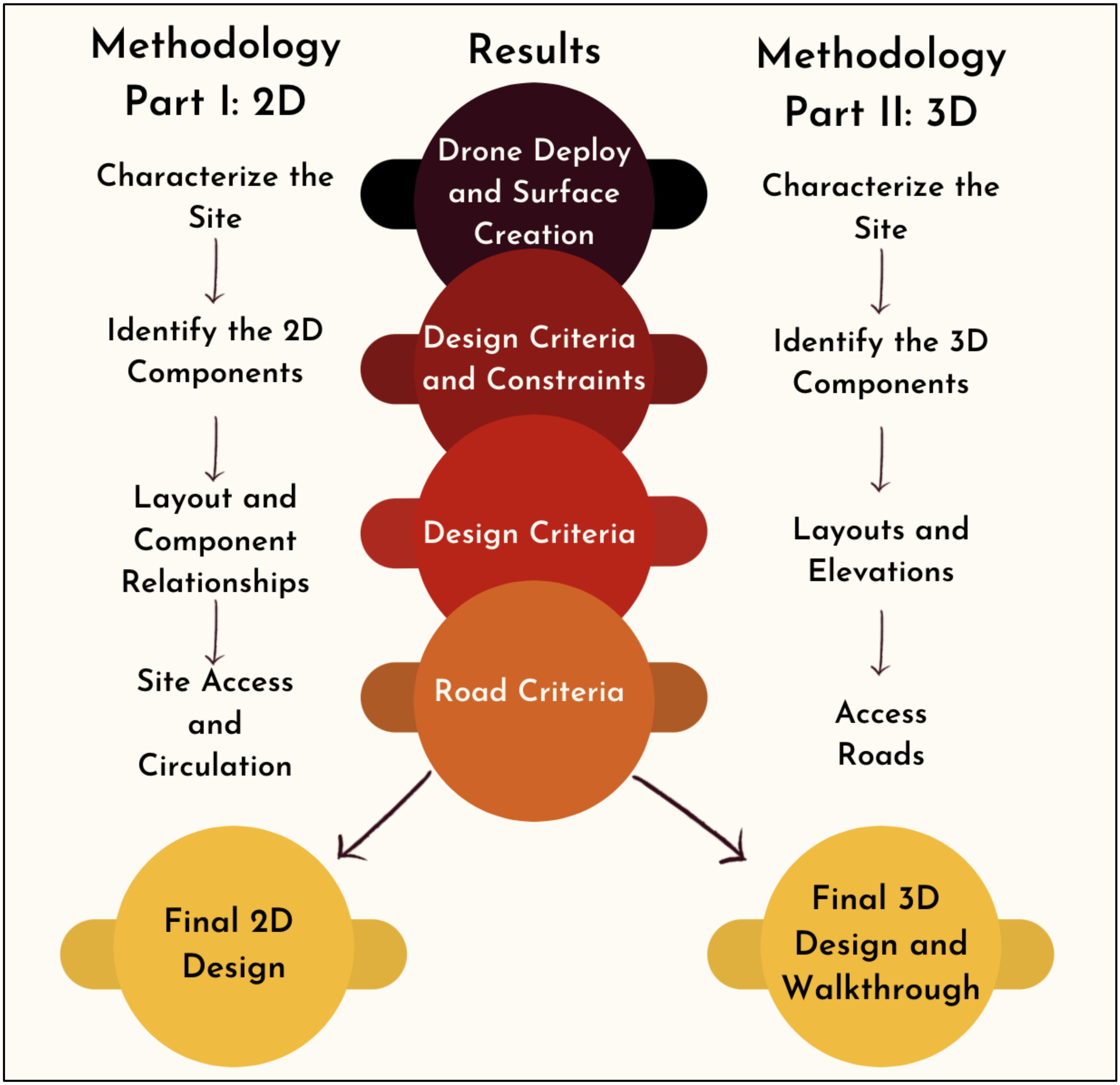


Figure 3.2. Methodology to Results Flowchart.

3.1. 2D Site Design

Part one of the methodology details all the necessary steps the team took to create the 2D site design.

3.1.1. Characterize the Project Site

To gain an initial understanding of the purchased land, data was gathered using DroneDeploy, Google Earth, GIS images, and site visits. The site analysis summary seen below in Figure 3.3 was the site purchase comparison detailing the metrics used by the ASADA when performing the initial analysis of these plots. The main criteria when choosing a site were technical, financial/economic, and socio-economic criteria. Technical criteria examined aspects such as total site area, access to infrastructure, topography, and legalities such as a deed. The chosen site in this grouping has 6.7 hectares of buildable area, access to a public road, steep topography for elements utilizing gravity, and a legal deed. The overall buildable area was very important because it was ultimately going to be divided between the ASADA and Municipality with joint ownership. The site components that provided benefit to either entity would then go on their portion of buildable area. The next category was the financial/economic criteria which main points of interest included cost per square meter, total cost, and estimated transfer cost. The main limiting factor for the ASADA is their funding from the Municipality, so finding a cost-efficient site solution was crucial. This made the decision clear in that Site 1 was only $11 per square meter of buildable site area which is an incredible value compared to the other two options of $100 and $68. The total cost was only $700,000 while also having the lowest transfer cost of $25,200 meaning this site was the clear winner for purchase. However, these financial benefits came with sacrifices as the socio-economic criteria made clear with the category of earthwork. Here it was determined the earthwork would require more than 300 cubic meters of soil to be moved to condition the site for construction. As this one of the most important parts of any construction project, the team would later perform a calculation to find the exact quantity of earth movement.

Project: Monteverde Environmental Technology Park			
Analysis of alternative sites that met the first filters	**Site 1-TR**	**Site 2-AR**	**Site 3-606**
Technical Criteria			
Total area available for related elements of the PTAM (hectares)	6.7	1-2	1
Compatible with the objecives for the inter-institutional project	X		X
Favors compliance with internal setbacks (Art. 5, Regulations No. 39887-S-MINAE)	X	X	X
Adjoins a viable recieving body (permanent)	X	X	
Topography of the sector maximizes collection by gravity	X	X	
Hydrology of the corresponding sector compatible with conceptual design	X	X	X
Atmospheric conditions (favorable wind direction)	X	X	
It has a legel deed	X	X	X
Access to a complementary infrastructure (roads, aqueducts and electricity)	X	X	X
Financial-Economic Criteria			
Cost per m2 (US$)	11	100	68
Total cost (US$) min	$700,000	$1,000,000	$680,000
Esitmated transfer costs (US$)	$25,200	$36,000	$680,000
Implications for cost of the sewage system	High-Medium	Medium-Low	High
Effective space available to use different technological configurations	High	Medium	Low
Socio-Economic Criteria (according to terms of an EIA)			
Probably requires earth movement ≥300m3	Yes	No	Unknown
Probably generates negative social impacts	No	No	Yes
Probably generates negative cultural impacts	No	No	No
Probably generates negative environmental impacts	No	No	No

Figure 3.3. Analysis of Alternative Sites for PAM. Site 1-TR was ultimately selected (Welch, 2021).

As a result of this preliminary site investigation, the team was able to deduct basic characteristics of topography, buildable area, and amount of forest cover. Another important product of this investigation was the property boundaries that could be overlaid on any further aerial imaging the team sought to procure.

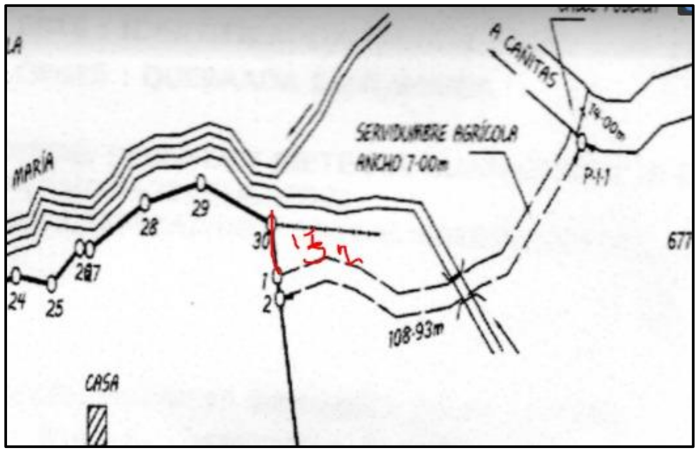


Figure 3.4 Stream shown in GIS layer (Chinchilla, 2022).

One notable feature of the site was the stream bed shown in Figure 3.4. This stream runs along the northern edge of the property and requires a 15-meter riparian buffer zone to preserve the water quality.

The first method of characterizing the project site was a site visit where the team conducted a walkthrough of the property upon arrival to Costa Rica. This proved to be extremely beneficial as all the features of the site could be visualized and put into context. For example, the team vastly underestimated the slope of the site, and it wasn't until seeing it in person and driving on the roads that it could fully be comprehended (Figure 3.5).

Figure 3.5. Photos of the project site from the team's initial site visit.

As the walkthrough was being conducted, workable data models for the design and engineering software were being produced through DroneDeploy. The company DroneDeploy has a multitude of useful applications that take advantage of the latest drone technology advancements to assist in all stages of the construction project. With help from Randy Chinchilla, a local geographer and drone pilot from the Monteverde Institute, high-resolution digital replicas were produced for the site that showcased many aspects of its current conditions. The DroneDeploy digital site mapping capabilities are showcased in Figure 3.6 below.

Figure 3.6. Example of DroneDeploy technology (Ordiz, 2017).

A subsurface investigation was another form of data collection that was intended for this project. No soil data was available publicly, so the team suggested that the ASADA contract out a preliminary study of the site's geotechnical properties and soil strata. This would assist greatly with the preliminary construction process producing greater knowledge of workable soil on the site, the exact depth of topsoil to be stripped, and any unknown obstacles a site work crew would face when conditioning for construction. A typical subsurface investigation would include borings at a depth of 50 to 100 feet (15-30m) and test pits that go to a shallower depth of 10 to 30 feet (3-9m). The borings would be used to provide a sense of the soil strata and water table while test pits would be used to provide much wider coverage of the site's subsurface conditions and usable earth quantities. A subsurface investigation is also used to collect soil samples from which simple laboratory tests can confirm the moisture content, density, unconfined compressive strength, and location of the water table. This information is all relevant to the project as phases 1 and 2 involve site conditioning and initial PTAM development. Unfortunately, this process did not coincide with the ASADA's project timeline and the heavy cost of performing such an investigation was out of the current budget. It will most likely be performed later in the preliminary construction process after the completion of this project. Therefore, no report of the subsurface soil conditions will be present in the results (more detail in Chapter 5.2 Limitations).

3.1.2. Identifying 2D Components

The transfer center was the main component and focus of this site design. It has many elements essential to the success of the Environmental Technology Park. The center needed to feature a tipping floor to fill WB-50 truck trailers, storage for machinery, an office and break room for employees, two separate loading zones, and a processing area for recyclables. The tipping floor requires two WB-50 trailers to fit in a staggered formation inside the building. The center also needed to have five loading bays for WB-50 trucks because there will be four types of waste processed in the center: recyclables, unprocessed recyclables, organics, and non-recoverable. These will cycle through the center and an extra bay was added in case those bays become full to account for future need. Figure 3.8 shows the average weekly produced tonnage of waste that the plant is expected to handle. It shows that the majority of space that is used in the center will be for recyclables. Therefore, the center needed to have a zone for unloading unprocessed recyclables and processing recyclables.

WB-50 trucks have a width of 2.5 meters and their trailers are 16.7 meters long (NCHRP, 2003). Loading docks should be spaced 3.65m apart (Nova Technology, 2017). Upon learning the needs for the transfer center, it was determined that having two floors would be best because it would utilize the natural slope of the site for the tipping floor. The bottom floor would be where the WB-50 trailers would be stationed beneath the tipping floors. It was also determined that the second floor would have to be leveled and graded with a retaining wall, because of the slope of the site. This would allow for the tipping floor, loading and unloading zones, and the processing area to function properly.

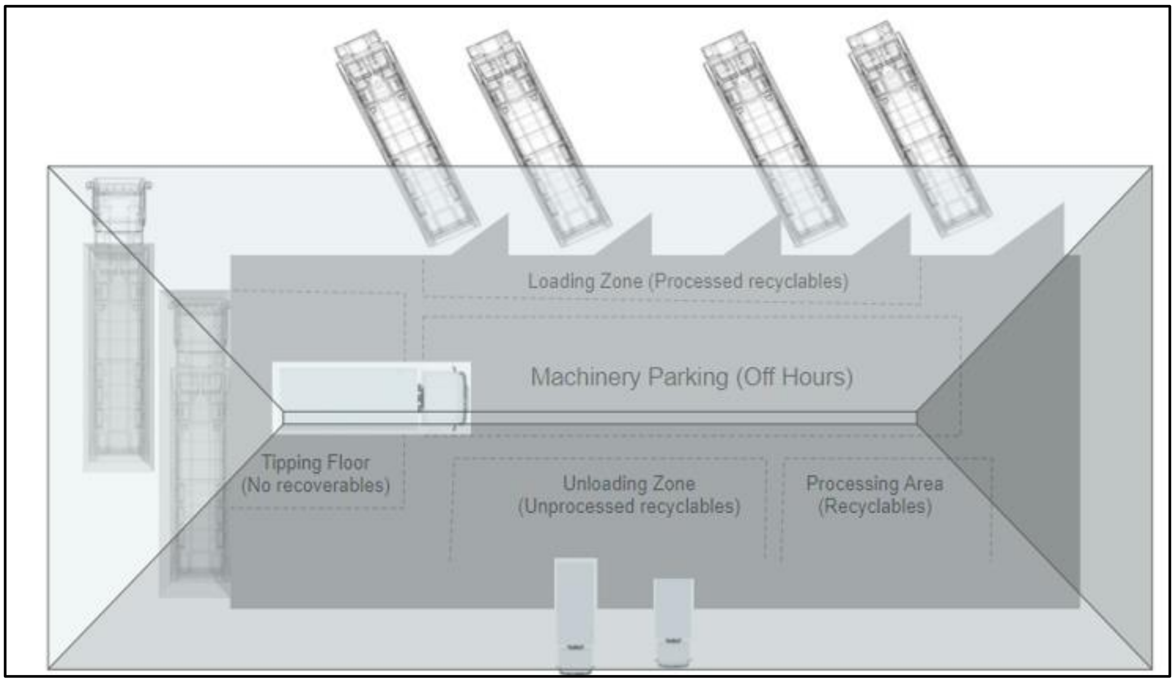


Figure 3.7. General Layout of the Transfer Center Main floor (Welch, 2021).

Type of Waste	**Average produced (tonnes/week)**	**Storage required in SWTC (m^3)**
Non-recoverables	21.8	Going directly to the compaction truck - no storage space needed in the SWTC
Recyclables	10.8	797
Organics	29.1	240

Figure 3.8. Space required in the Transfer Center for each type of waste in 2045 (Welch, 2021).

The site also needed another area that is easily accessible where residents of Monteverde could come to drop off waste such as household items, organics, electronics, etc. Therefore, a public drop-off center was added to the design. To be consistent with the loading docks, space was allocated for 5 different waste bins, one for each type of waste and one extra. Similar to the transfer center, two levels were chosen for this area. The upper level would be where public cars could go to drop off their waste. The lower level is where the bins would be placed. The benefit of this elevation difference is the ease of access for vehicles, no heavy lifting of waste, and access to the containers would occur in a different area. This ensures commercial trucks would be able to lift the waste bins and unload them without interfering with public vehicle traffic. The last components added to the drop-off center were two extra collection bins the north of the public drop off area to accommodate additional waste.

Figure 3.9. Tiered public drop off example (Deffenbaugh, 2022).

The Wastewater Treatment Plant (PTAR) was the next component of the PTAM. It required various structures in order to complete the treatment system. The requirements were an intake/screening building, a homogenization or sedimentation tank, an anaerobic reactor , a percolation filter, and lastly a secondary settling tank. One of the major considerations for the PTAR was spacing of the component structures. Keeping the buildings close together will require less piping, therefore keeping the overall cost down. Another reason shorter spacing was chosen is because it may be beneficial if the system was to be gravity fed as steeper elevation changes over shorter distances can speed up flowrates in pipes.

The next site component was the Productive Treatment Plant (PTP). Prior to the start of the project, the ASADA already had a small-scale PTP system in place that was one level and had 4 tanks, pictured below in Figure 3.10. The new system will be larger with four terraces and would take advantage of the grade by having each step of the process right below the next (Figure 3.11).

Figure 3.10. Current small-scale productive treatment plant in Monteverde (Welch, 2021).

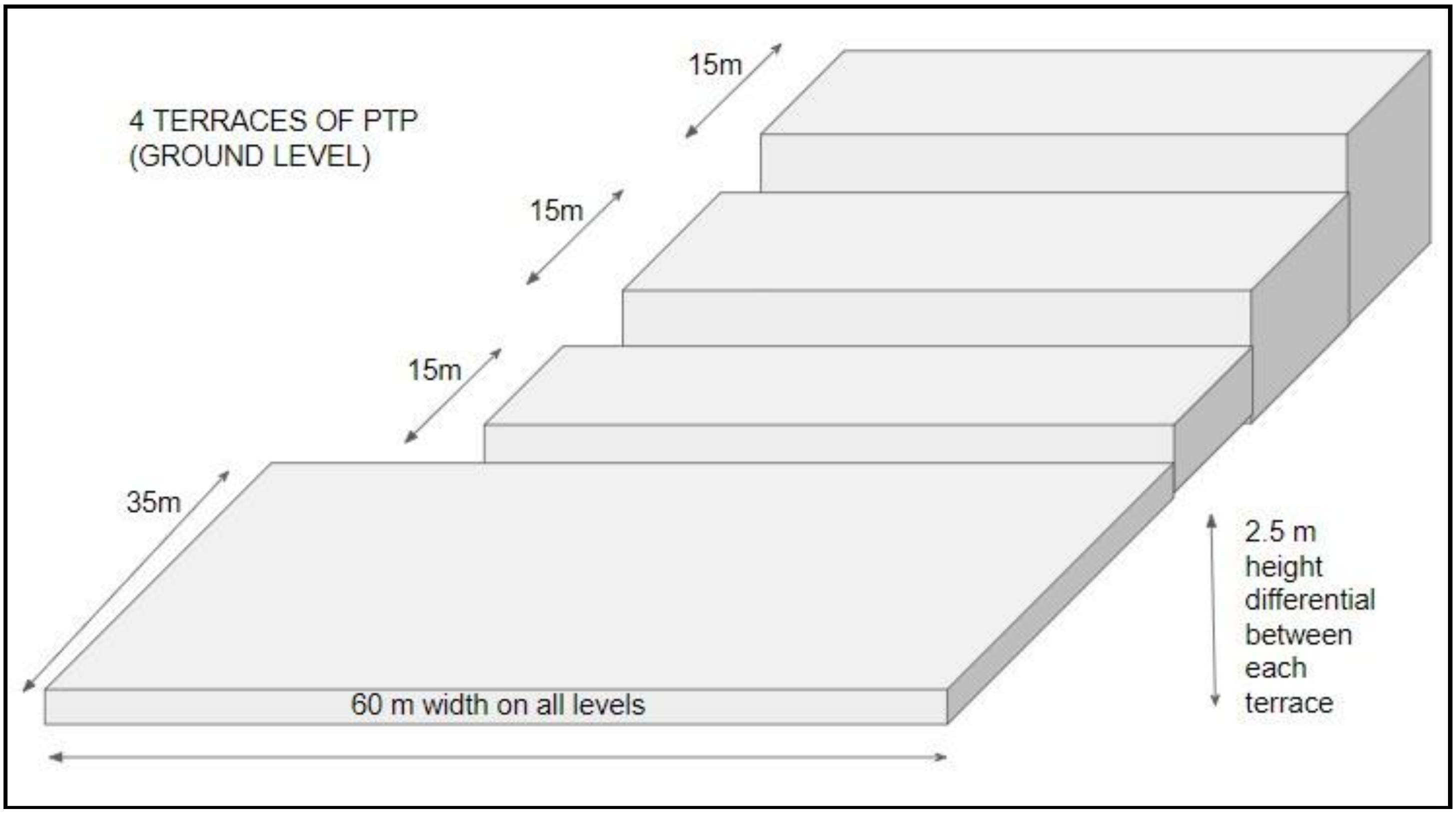


Figure 3.11. Proposed Productive Treatment Plant design for the Environmental Technology Park (Welch, 2021).

The needs for the site went beyond just the treatment buildings and transfer center. The PTAM also needed a weigh station at the entrance. The WB-50 truck was selected as the design vehicle because it is the largest truck that will be used on the site. A small building at the entrance was also necessary. This office needed to have a space for the employee to work, a bathroom, and a room for storage.

Workshop buildings were also requested from the project sponsor. These buildings would house different equipment. One building may house a welding workshop, electromechanical equipment, or any other materials or equipment. The last component needed for this site was an administrative office. The office needed to have room for two double offices, a conference room, two bathrooms (one handicap), a kitchen, and a general reception area.

3.1.3. Layout and Component Relationships

After gaining a comprehensive understanding of the different site components and their associated design criteria, the next step was arranging them on site. The transfer center's location was the first to be determined as it was the largest structure and demanded the most real estate to function. The first requirement for the transfer center's location was it had to be on Municipality-owned land which is indicated as the red area in Figure 3.12 below. Another constraint that was accounted for in the placement of the transfer center was the intended two-level design that would ultimately take advantage of the elevation change on site. This meant that the whole center had to be oriented around one of the slopes and the loading trailers had to be positioned on the downhill side of the building.

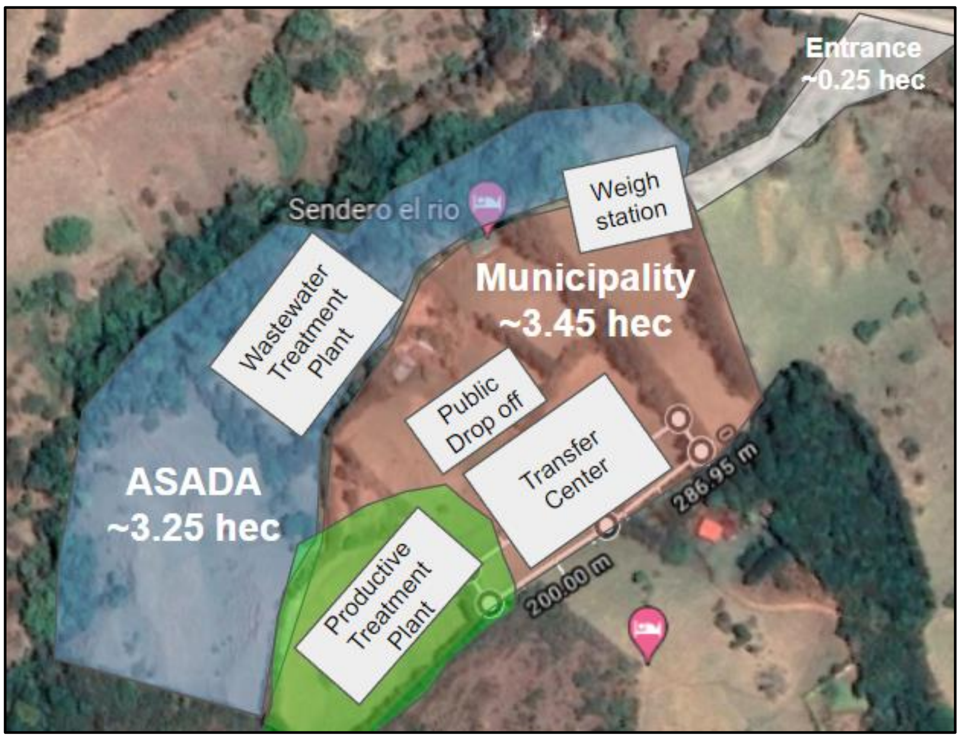


Figure 3.12. Project site approximate area designations (Welch, 2021).

The division of the site shown above (Figure 3.12) was made mostly due to natural site features like the existing internal road and buildings. This naturally divided the land between the Municipality and ASADA and the ASADA needed land at a lower elevation for their gravity fed wastewater treatment plant, so they received the western portion. Moving onto the productive treatment plant, this was a relatively simple component to place on the site as it already had a designated area in the Southwest region of the site. It had many reasons behind its placement including it split the land owned by both the ASADA and the Municipality who both sought to benefit from this component. Another reason was that this section of land formed a natural barrier from the rest of site because it sloped towards the south and away from both the ASADA and Municipal land. The southwest region past the site boundaries is also conservation land meaning the tree cover serves to minimize odor and visibility while also ensuring there are no neighbors to potentially be affected. The process of harvesting resources from organic waste can produce intense odors and ensuring proper barriers to the neighboring land and populations is an important aspect of choosing a destination for this component. As mentioned before, this section of land sloping away from the rest of the site allowed the treatment plant to take advantage of the elevation changes on site in its final design.

Placement of the ASADA's wastewater treatment plant proved to offer the most flexibility with only a few constraints for location. It had to be below the elevation zero contour line to allow for a gravity fed system that originated from the public road at the entrance of the site. The only other constraint as far as location of the plant was that it had to be oriented so the treatment train operated on a decline in elevation. This meant the pre-treatment component needed to be closest in distance to the entrance and the highest in elevation as sewage for treatment would be pumped from the site entrance.

The last major component that needed to be located on site was the weigh station. The team knew this had to be placed as close to the entrance as possible but without interfering with the legal property boundaries. Since it served two-way traffic, it had to be oriented so that it could receive trucks and public vehicles easily in both directions.

3.1.4. Site Access and Circulation

As general locations for buildings were determined, the access and circulation of traffic through the site started. The entrance road to the site was quite narrow at 3.3 meters (10.8 feet). The existing access road is also at a 90 degree turn off the main road. With these factors considered, access for large semi-trucks is not feasible. The entrance road can be seen in Figure 3.13. It was clear to the group that this road needed to be widened to accommodate two-way traffic and the turning radius of WB50 trucks.

Figure 3.13. Project site road entrance (Welch, 2021).

Besides the entrance road there were no previous roads going through the site, giving the team freedom to design the road in the most feasible way. The road needed to allow access to all site components while keeping conscious of the space on-site that it took up. The biggest constraint of the access road is the largest truck that is going to use it which would be a WB-50. This means that every corner and turn in the road must support the accessibility of the large truck. The WB-50 truck has a large turning radius, for both the inner and outer tires. To address this, a turning radius template from AASHTO regulations was created in Bluebeam Revu that could be placed on different corners to ensure the trucks would be able to navigate the road system. The template can be seen in Figure 3.14. The inner circle is in relation to the inner tire, which needs 22’ to do a full 90-degree turn. The outer circle represents the space needed for the outer wheel to do a 90-degree turn, which is about 48’. The template was placed on corners that looked sharper in order to ensure proper accessibility. In some instances, this was conservative as not every turn was as sharp as the template accounts for.

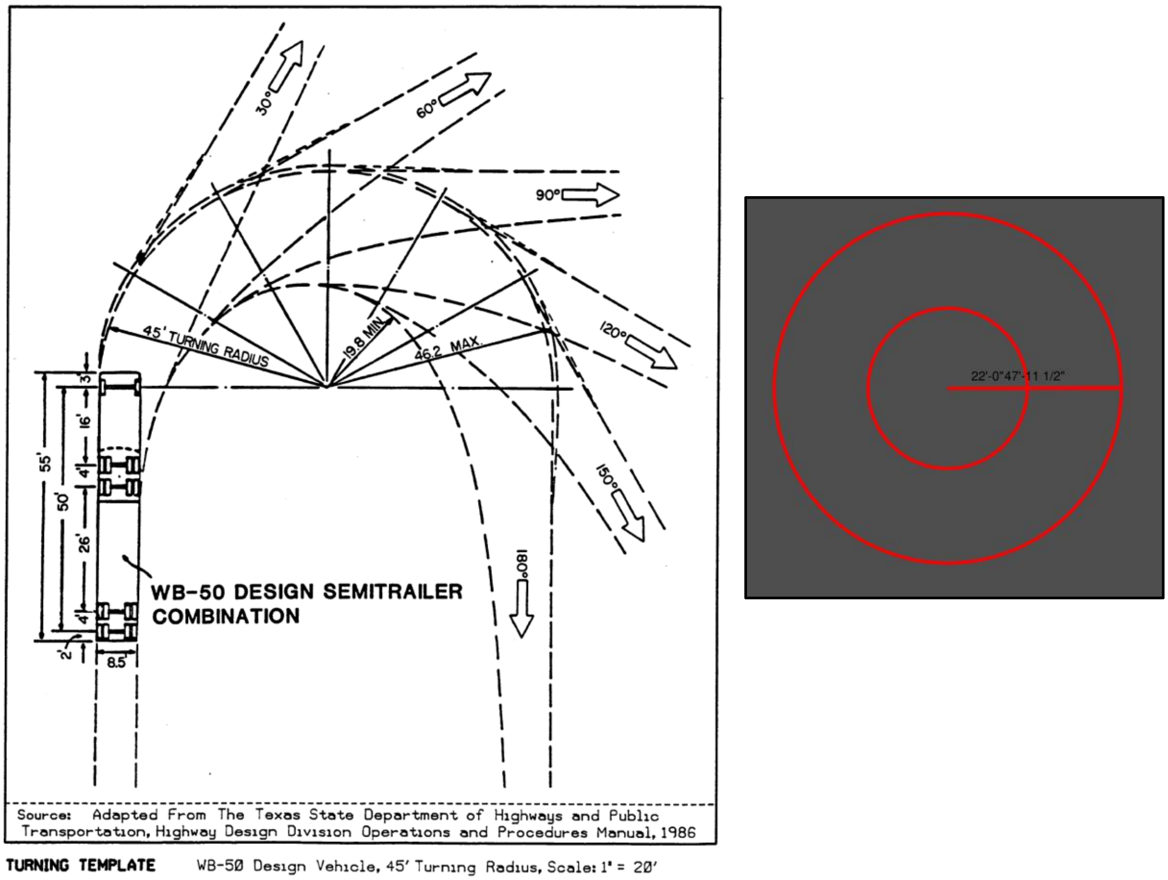


Figure 3.14. Turning radius of WB-50 truck and template created by the team (AASHTO, 2020).

3.2. 3D Site Design

This phase of the methodology discusses the steps the team took to create 3D models. After all the 2D Site criteria were considered, it was necessary to design the site in 3D and introduce a whole new set of criteria. This further enhances both the feasibility and usefulness of the overall design.

3.2.1. Characterize the Project Site

The first step of creating a 3D design was procuring data that the Autodesk Civil 3D software could manipulate. This ultimately involves characterizing the project site through the creation of a 3D digital model highlighting all the features and their elevations. The starting point for this model was the data from the DroneDeploy flyover. It came in the form of a drawing file that contained polylines over the entire boundaries of the drone scan that represented all the elevation contours. In this case, the polylines were only drawings on the screen with associated elevations as their description. Figure 3.15 below shows the contour drawing file exported because of the DroneDeploy process.

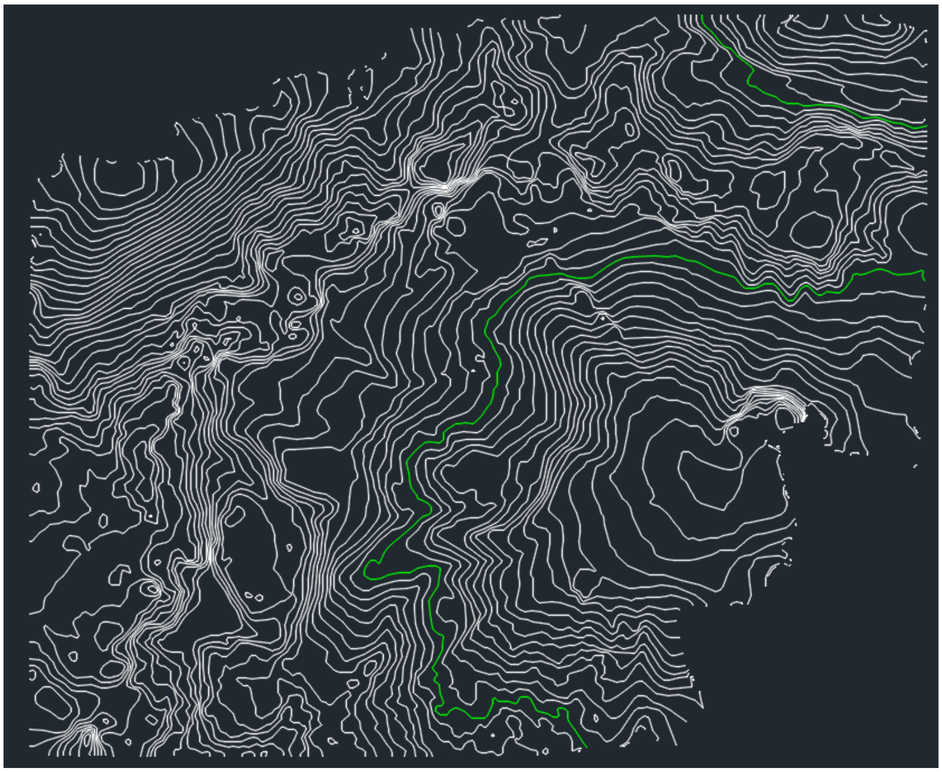


Figure 3.15 DroneDeploy elevation data in contours.

The one polyline that is highlighted green is the contour line resembling elevation zero which is the elevation of the public road at the site entrance. For them to be useful to the 3D model, these elevation descriptions had to be translated onto similar feature lines in the same drawing. The reason for this is the feature lines had an “intelligence” that the Civil 3D software could recognize and manipulate. Instead of just being described at a certain elevation, they reside at their assigned elevation within the software. The next step was transforming these newly created feature lines into a continuous surface model of the existing ground on site. This involved placing the lines within a joint site for the software to process into a TIN (Triangulated Irregular Network). This maps out the elevation points of each feature line and connects them with triangle features to ultimately become the surface the rest of the 3D site design is based around.

3.2.2. Identify 3D Components

After the base surface was modeled in Civil 3D, the site components and their changes to the existing grade had to be represented. This involved understanding the different site components and their demands on the surrounding topography by underlying the 2D site design below the surface. Without delving into any architectural work of the buildings themselves, this focused on criteria such as building plots, their finished elevations, and the grade of surrounding land.

Like the 2D site design, the first component that was characterized in the 3D model was the transfer center. The focal point of this component was the elevation difference between the lower and upper level of the building and the corresponding retaining wall that was required. This involved bringing the transfer center from the 2D underlay into the model as polylines. Just as the contour line surface was made these polylines were turned into feature lines and assigned elevations at every data point along the line. To replicate the retaining wall, the building plot was split into two sections each with different elevations. The tipping floor and trailer loading area were made to be flat foundations and separated by five meters of vertical space. To ensure this was carried out by the model, break lines were added to the surface making all rendering and grading calculations account for the five-meter retaining wall. The public drop off area also needed a three-meter elevation difference for public vehicles to drop trash into containers below. Another feature of the transfer center that was considered for the 3D model was the down ramp built into the east side for the truck loading bays. This would allow the trucks to back down into the truck ports and align their beds with the level of the tipping floor. The final considerations for the 3D transfer center were the space needed for the WB-50 trucks to align themselves with the loading bays and the area designated for recycling drop-off. These both had to be graded into the land surrounding the final placement location of the transfer center. An example of the feature lines that resemble the transfer center building pads, truck bays, and access pavement can be seen in Figure 3.16 below.

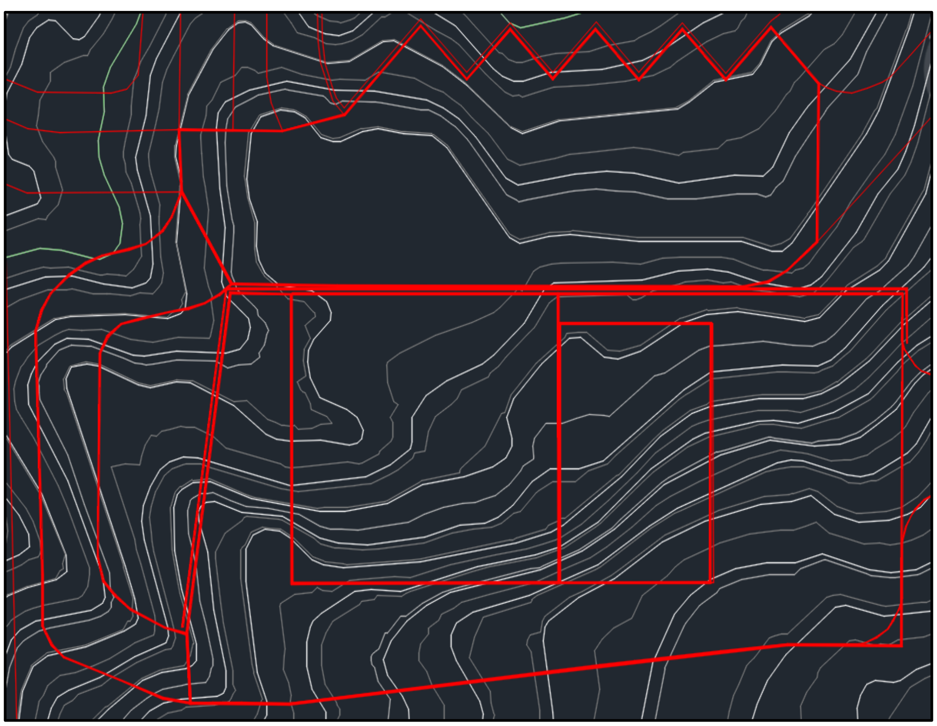


Figure 3.16. Transfer Center plotted on the existing ground surface in Civil 3D.

The next component was the productive treatment plant and its associated grading tiers. This was a relatively simple component and only required proper elevation spacing between the four levels involved. This elevation difference between each level needed to be enough to transfer the organics easily between levels and phases of treatment. Another component that needed more earthwork and grading considerations was the wastewater treatment facility. This along with the whole area being allotted to the ASADA needed to be terraced in a manner that left a half meter between each level. The selection of final elevations of these plots would also need heavy consideration due to their wide spans across the site. The other "terraces" that had to be considered included the administrative offices with corresponding parking, the weigh station, and the undesignated land on the east side of the site that had to be split into two platforms. Similar to the wastewater treatment plant, these all had to account for large elevation changes over spans across the site. The final component on the 3D site design was the entrance road and the graded pads that would support the bridge over the stream. This shaping of the land up to either side of the bridge had to blend into an existing grade on the surface and then meet at a similar elevation.

Once the 2D design was completed the team was able to think about the components from a 3D standpoint. All of the necessary structures were created in AutoDesk Revit. To create the buildings the basic order of functions in Revit were followed: first the walls were placed, then the first floor, second (if needed), a ceiling (if needed) and roof, and finally the furnishings and other detail items. RevitCity, a free online tool with pre-built models, and the existing WPI libraries were used to furnish the buildings. All the components are to scale and can easily be edited in the future if needed.

The 3D designs began with the transfer center. To determine the height difference between the two floors the height of a WB50 truck needed to be accounted for, which is just over 4 meters (NCHRP, 2003). The height of the roof from the second floor was another dimension that had to be chosen, as machinery will be kept there. The largest piece of machinery that needed to be accounted for was a backhoe (approximately 4 meters). The team was able to load in a backhoe from RevitCity that was 3.91 meters tall.

3.2.3. Layout and Component Relationship

After the team established the components within the 3D model, their placement on the site and overall relationship to one another had to be considered. This involved running a grading optimization on the building plots, surrounding pavement, and the overall terraced areas. The grading optimization is a calculation run by the software and is governed by user inputs. Before running the optimizer, the site boundaries and legal setbacks determined from the 2D site design had to be added to the 3D model in the same process as the building plots. The pdf of the site design with the property boundary, riparian buffer, and wastewater treatment boundary were underlaid and the polylines were rendered onto the existing ground surface as feature lines. At this stage the project team also decided to designate an area along the western boundary of the site for erosion control. The intense topography as well as the close proximity to the neighboring environmental conservation made this a logical decision to preserve the land as well as use this for any

Figure 3.17. Grading Metric from Civil 3D.

excess material created for site preparation. Now that all the potential components and influencing factors were added to the file, the user had to filter these feature lines into grading metric categories that the program could understand. An image of all the potential categories for the grading calculation can be seen in Figure 3.17 to the right. This process of assigning these categories was straightforward as it allowed direct input of building pads, retaining walls, reveals, etc. The property boundary even served a purpose by becoming the governing zone for maximum and minimum slope criteria. The legal setbacks previously mentioned were combined with the newly created erosion control zone to serve as the grading limit for the optimizer. In Figure 3.18 below the transfer center building pad and surrounding grading zones can be seen after being placed in the grading optimization program.

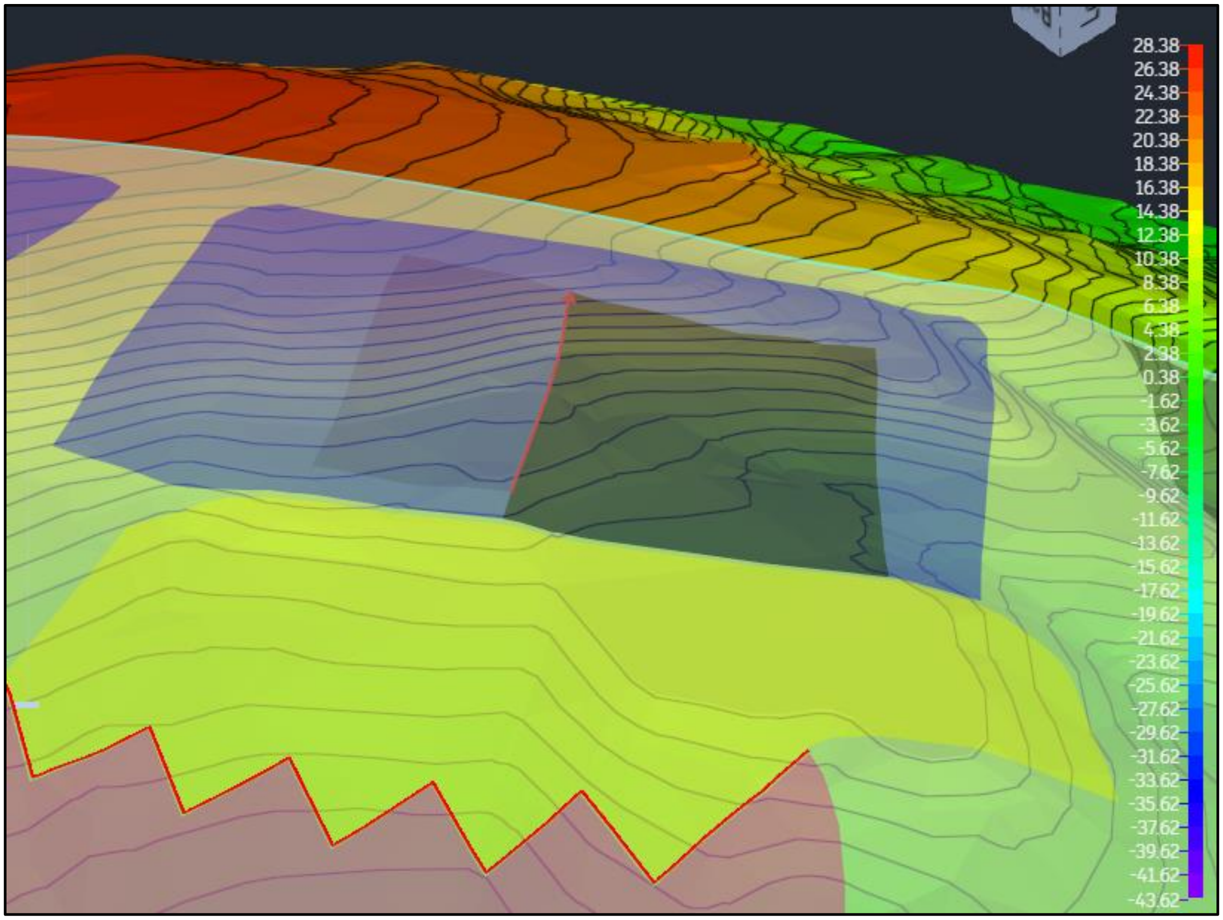


Figure 3.18. Transfer Center Building Pad and surrounding grading in Civil 3D.

For the building pads, an input range of possible finished elevations as well as relationship to other zones and building pads was established for the calculator to decide the best outcome. In many cases, including the public drop off, transfer center, and productive treatment plant, the terraced land was tied by an intended elevation separation to enhance their functionality. Then after the grading optimizer was set up with all these components and their influence on one another, the calculation was conducted. This process involved testing an immense amount of possible grading schemes within the given parameters to output the best possible final 3D design. It also outputs total earthwork quantities like cut and fill volumes to explain the feasibility as well as the work necessary to condition for construction.

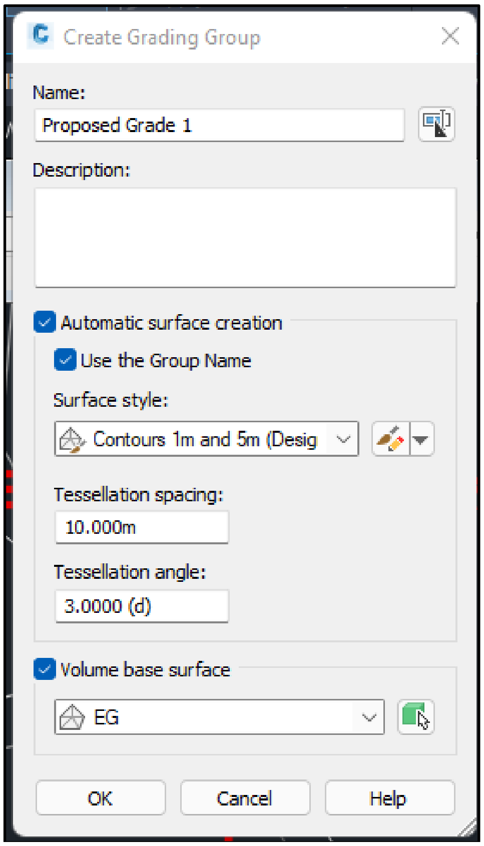


Figure 3.19. Grading Group Creation.

After the final elevations were procured from the grading optimization, the building components had to be physically set into the existing ground surface to create the 3D earthwork model. This involved creating new grading groups that were set to become additions to whichever volumetric surface was intended. In Figure 3.19 to the left, the process of creating a new grading group can be seen. The grading and surface process could be streamlined with the automatic surface creation feature as long as the intended volume base surface was known. This volume base surface is the layer that the new proposed grades, such as the plot for a building, would ultimately be set into creating a merged output surface of the proposed and existing grades. This became a very complex process once features had to be layered on top of one another such as the upper layer of the public drop off had to be graded down onto a surface already containing the grades from the lower level. After inputting slope criteria and creating infills, the components were all turned into volumetric additions to the existing ground surface. Breaklines were then added to the surface where retaining walls belonged as a method of preventing the earth from sloping down to the existing model.

3.2.4. Site and Component Accessibility

After adding all the components, the 3D model needed to be finished with the connecting road infrastructure. There was already an understanding of the road and traffic flow in a 2D horizontal sense but introducing the factor of elevation made it a much greater challenge. The optimizer was run again with the added road zones to gain updated quantities of earthwork after this new grading criteria was implemented. After this it was on the user to manually construct the road connections between site components and ensure feasibility standards were met with the allotted space. An example of the elevation input process while editing the feature line elevations can be seen below in Figure 3.20.

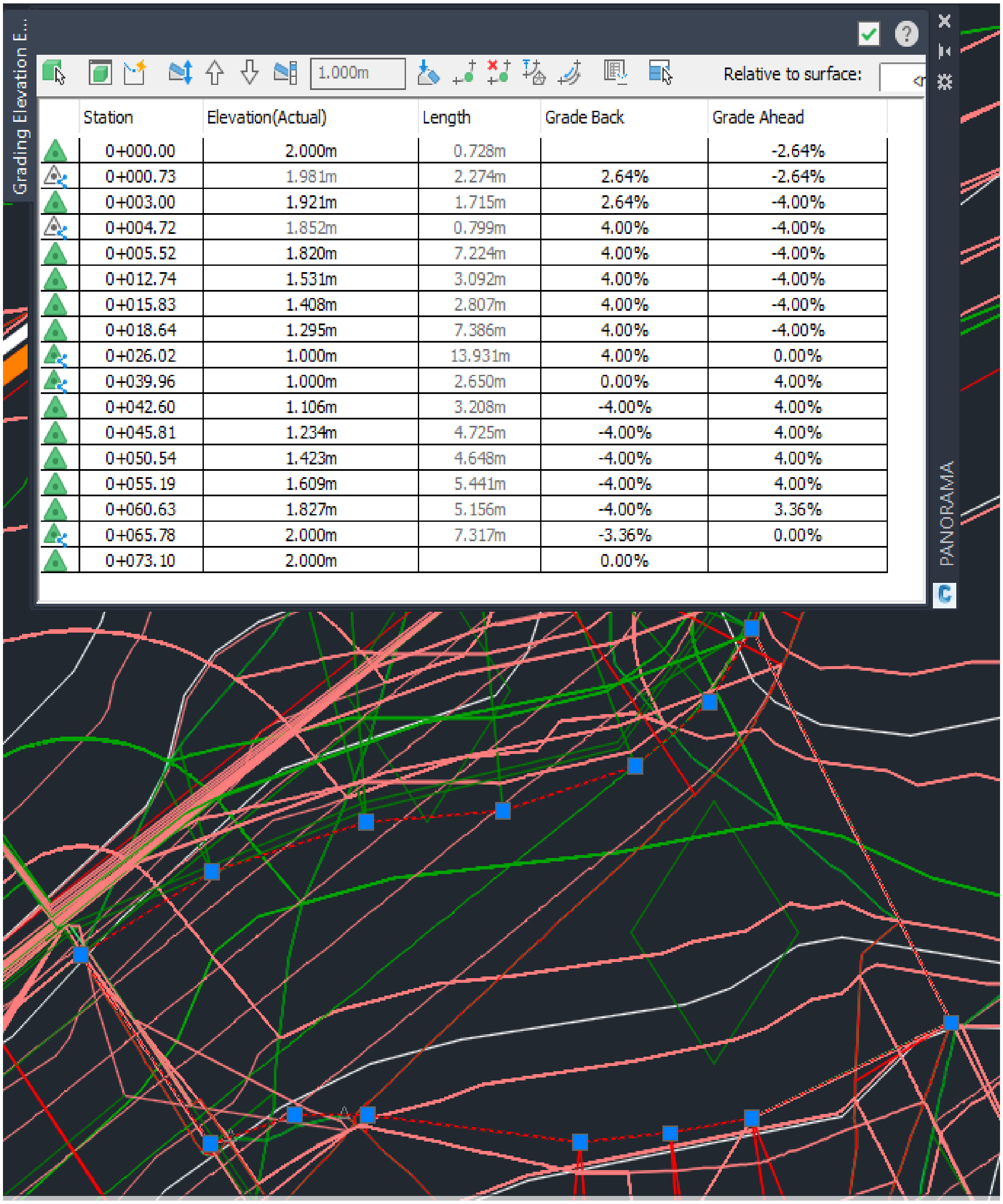


Figure 3.20. Example of the elevation input process while editing the feature line elevations in Civil 3D.

This final step of adding the road grading to the 3D model followed a similar path to the component grading and automatic surface creation. Additional grading groups also had to be created and since the roads were connecting already existing surface grades and a new surface had to be created for each road bed. The road elevation editing, as seen above, only had a few constraints to consider which were the starting elevation, finishing elevation, and the maximum slope along the road to account for the elevation change. After editing the elevations of the grades, they were also merged onto a finished design surface and touched up with breaklines/leveling to ensure the best possible model was created.

4. Results

This chapter will discuss the results gathered from the steps outlined in the methodology.

4.1. Characterization

The characterization process provided a greater understanding of the workable site in both a horizontal and vertical sense. It also provided the team with the necessary data to start the 2D and 3D site designs. The first product of the characterization was the Google Earth imagery seen in Figure 4.1. This satellite image with the property boundary, legal setbacks, and total workable area can be seen below.

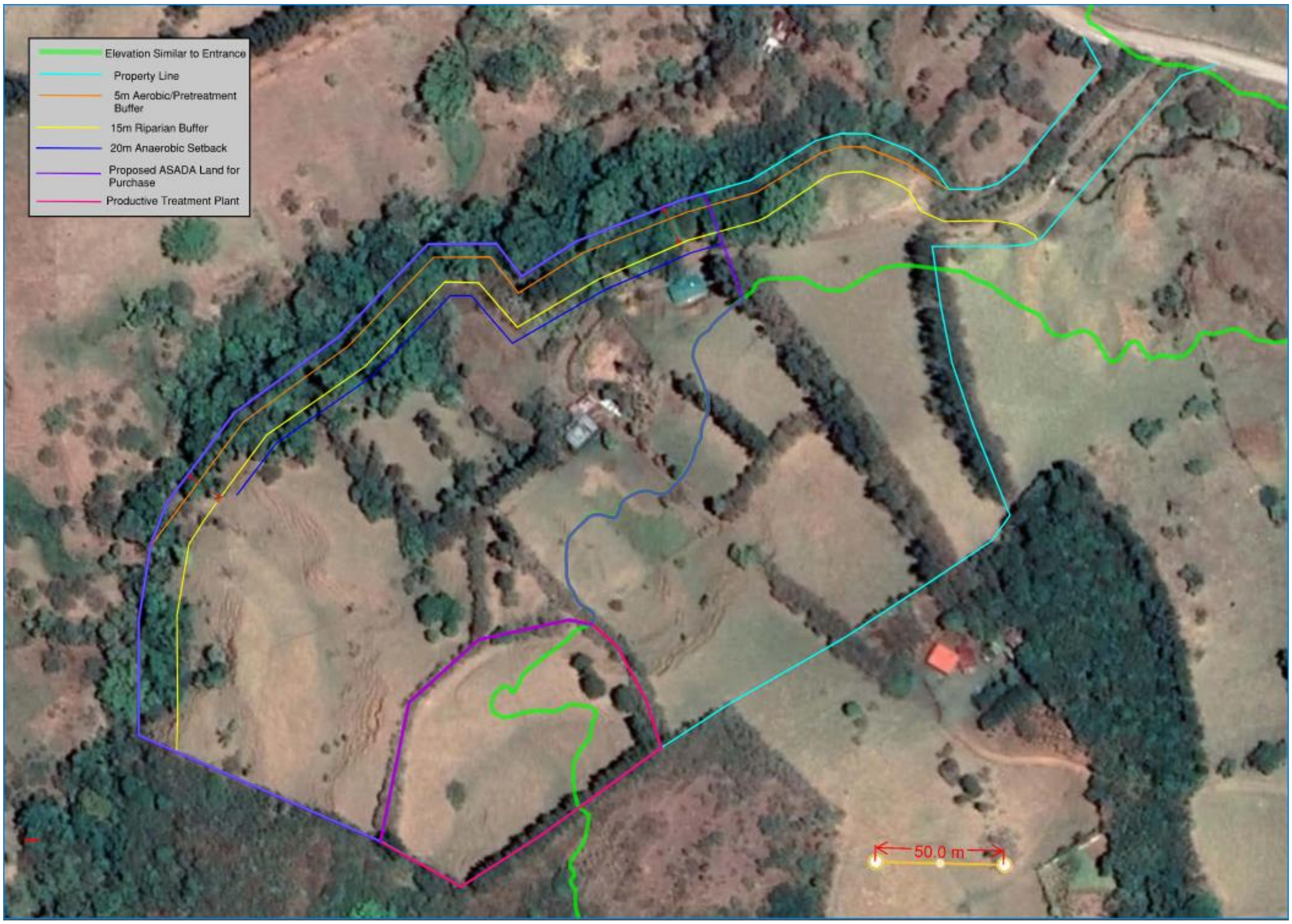


Figure 4.1. Property bounds and buffer constraints of the project site.

Due to the intended uses for the site as a transfer center, and productive treatment plant, and wastewater treatment plant, setbacks and buffer zones were taken into consideration. The riparian buffer is vegetation meant to protect streams, lakes, or wetlands in construction projects. The Ley Forestal 7575 Article 33 regulation in Costa Rica states that this zone needs to be set 15 meters away from the stream at all points (SCIJ, 1969). This impacted the buildable area on the norther part of the site while also making a bridge necessary at the site entrance for vehicles to traverse over the stream. Other setbacks were also necessary due to the type of technology that the ASADA would employ in their wastewater treatment plant. The Reglamento para la Aprobación y Ubicación de Plantas de Tratamiento de Aguas Residuales sets certain boundary laws for different wastewater treatment technologies from their property lines (Figure 4.2).

a) 50 meters from Anaerobic Lagoons, Sludge Lagoon

b) 20 meters of open units such as primary and secondary settlers with and without incorporated digesters, aerobic and aerated facultative lagoons, biological filters, anaerobic reactors, anaerobic biodigesters, artificial wetlands.

c) 10 meters of closed units such as primary and secondary settlers with and without built-in digesters, biological filters, anaerobic reactors, aerobic and anaerobic biodigesters, tanks with surface aeration, hermetic safety cells.

d) 10 meters of Biodiscs, tanks with surface or diffusion aeration, open and roofed drying beds, aerobic biodigesters, evaporation systems.

e) 5 meters of mechanized forced flotation units, homogenization and compensation tanks, flocculation and coagulation units, pumping stations, minor pre-treatment works (screens, sieves, grit traps, manholes, pipes and channels, grease traps) , chemical treatment plants, press filters, sub-surface infiltration fields.

f) 5 meters of small individual treatment systems for ordinary wastewater (flow less than or equal to 5 cubic meters per day) and, if applicable, their drainage.

Figure 4.2. Buffer zone for Wastewater Treatment Plant based on different technologies (Welch, 2021).

The PTAR is set to feature flocculation and coagulation units as well as primary and secondary settlers. For flocculation and coagulation technology a 5-meter setback from the riverbed is necessary; primary and secondary settlers require a 20-meter setback. Figure 4.2 below shows all the boundary constraints discussed. The 20-meter setback (blue line) was the controlling factor, but only on the northern part of the site due to the stream. This setback is also only related to the PTAR structures, meaning that although treatment structures cannot be placed here, roads can.

DroneDeploy produced the most data that could be used by the team to create the 2D and 3D site design as well as procure further useful data. The ASADA also benefited from the DroneDeploy flyover as they now have powerful visualization tools as the project develops through the preliminary construction phase over the years to come. Pictured in Figure 4.3 is the gathered orthomosaic of the site. This was a helpful tool throughout the design process as it clearly indicates all the site features as well as provides the most recent condition of the workable area within the property boundary.

Figure 4.3. DroneDeploy 3D orthomosaic of the project site.

This same view was provided by the DroneDeploy software in a raster digital image format as well. In a raster, the three-dimensional structure of Earth's surface can be visualized by shading of the land features that represent changes in elevation. Figure 4.4 below shows the full raster image export from the drone fly-over.

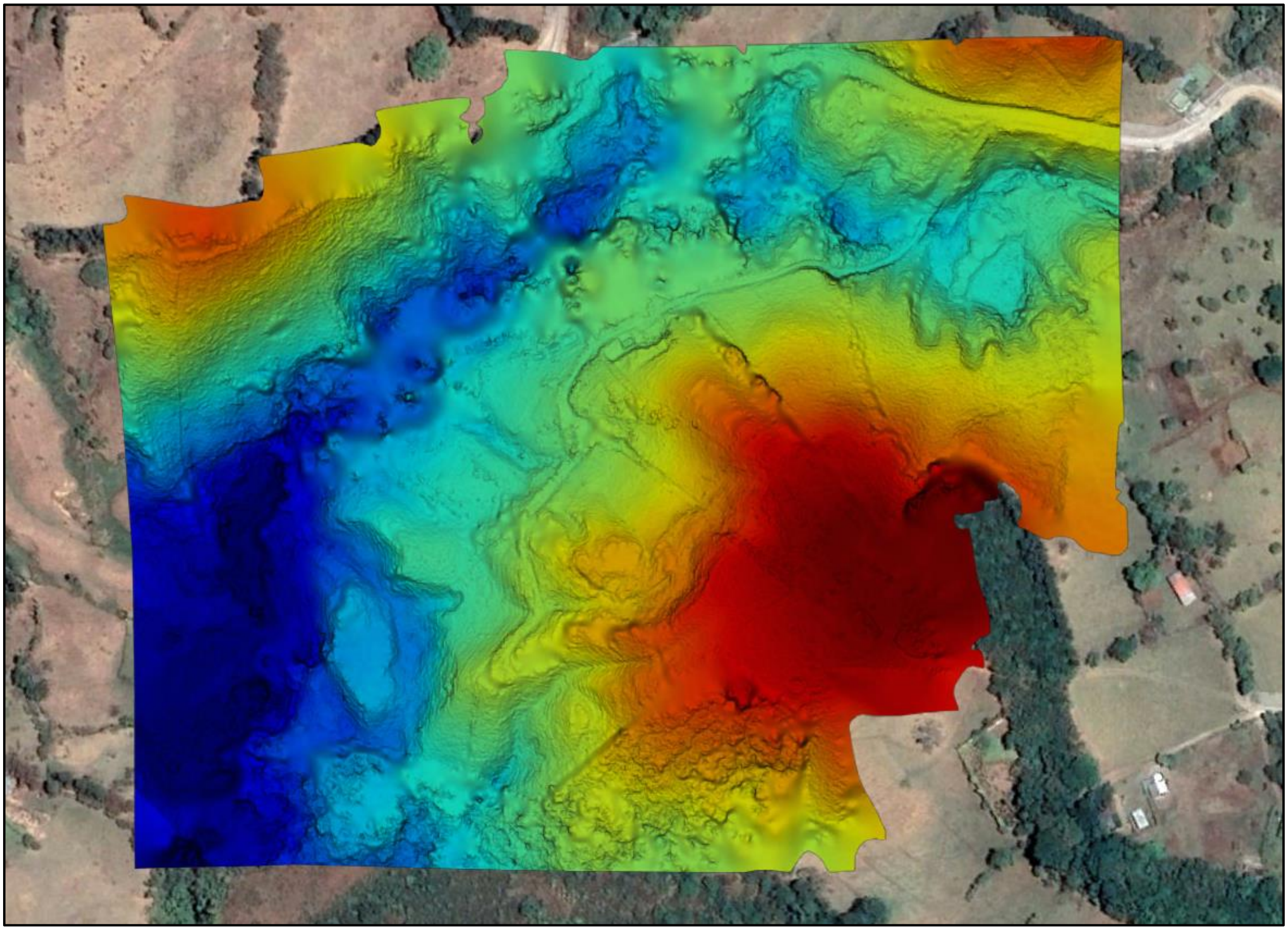


Figure 4.4. DroneDeploy digital raster image of the project site current topography (Chinchilla, 2022).

This image was especially useful as it reinforced all the site features the team could see from the site visit. As represented, the color yellow pertains to elevation zero which lines up with the public road at the entrance of the site. All the colors that are warmer than yellow are elevations higher than zero meaning the highest point on the site is the dark red area along the southeast border. The cooler colors represent all the elevations lower than zero with a lowest on site elevation being in the dark blue along the west border. This blue coloring that travels through the site showcases the stream bed that the team was able to visualize during the site walkthroughs. It also reinforces the property boundary that had been placed on the Google Earth satellite image as it followed directly along the stream. While this greatly assisted in visualizing the elevation changes across the site, the contour lines as last export from the DroneDeploy software assisted the most in providing mathematical elevation data.

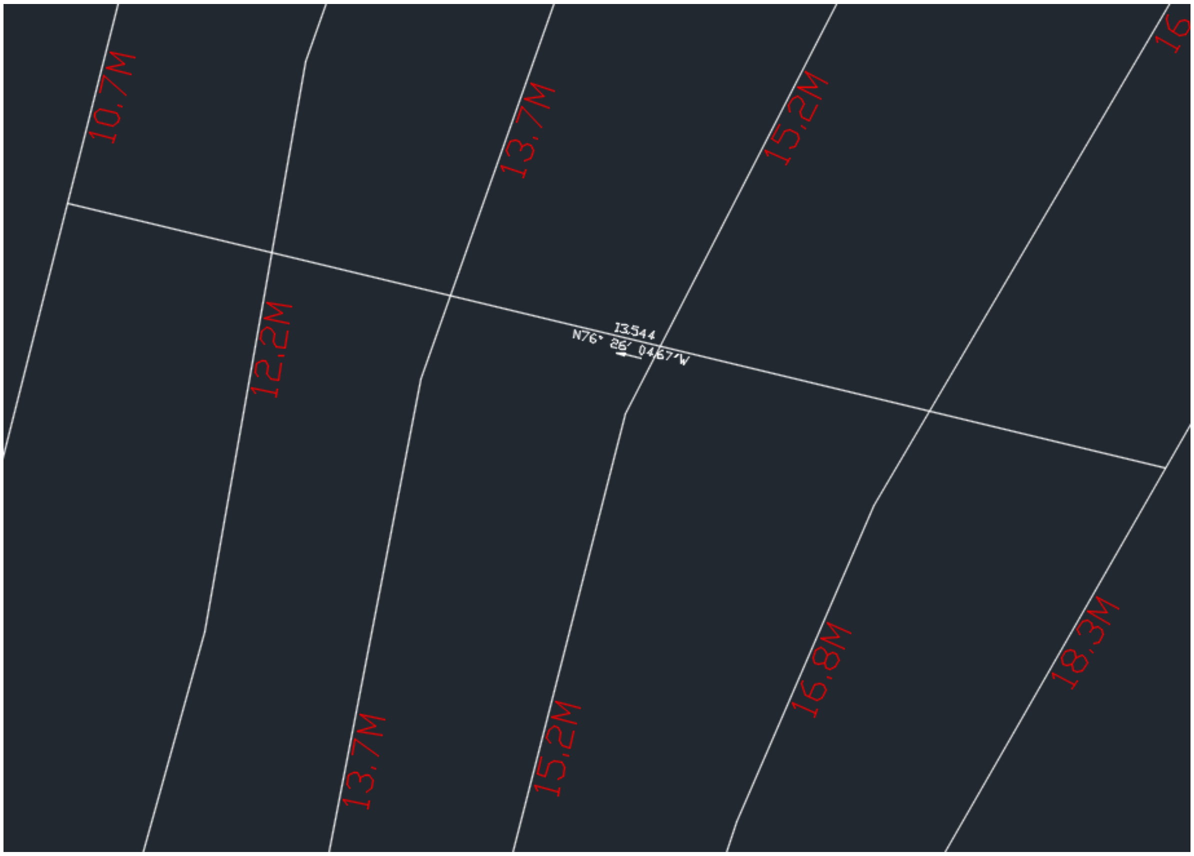


Figure 4.5. Contour grade data example.

As seen in Figure 4.5 above, this area of the site traverses 13.5 meters horizontally and has an elevation change of 7.6 meters. This equates to a grade of 56% which is just one of many similar sections of the site. To put this extreme grading constraint in perspective, all site building pads must be graded flat and the maximum slope in a road for large trucks is 5%. This is a massive disadvantage for a site design as roadways will take up much more space to make up for the large elevation climbs and descents. Building pads will also require more cuts and fills to level out all the horizontal real estate required for their support. Another metric taken from the contours were the highest and lowest elevations on site. The highest point located within the buildable site area is 24.4 meters above the public road while the lowest point is 20 meters below the roadbed. This possesses a total elevation change of 44.4 meters just within the area of the site that needs grading. With this data taken from the contours, the team knew the comprehensive 2D and 3D site design were not going to be easy.

With the last of the data taken and analyzed from the DroneDeploy software, the team turned to creating a 3D model starting point from the contour data. As outlined in the methodology, the contour polylines were turned in a continuous topographic surface that resembled the existing ground of the site. This 3D modeled surface can be seen in Figure 4.6 below and again in Figure 4.7 with the raster color formatting overlaid.

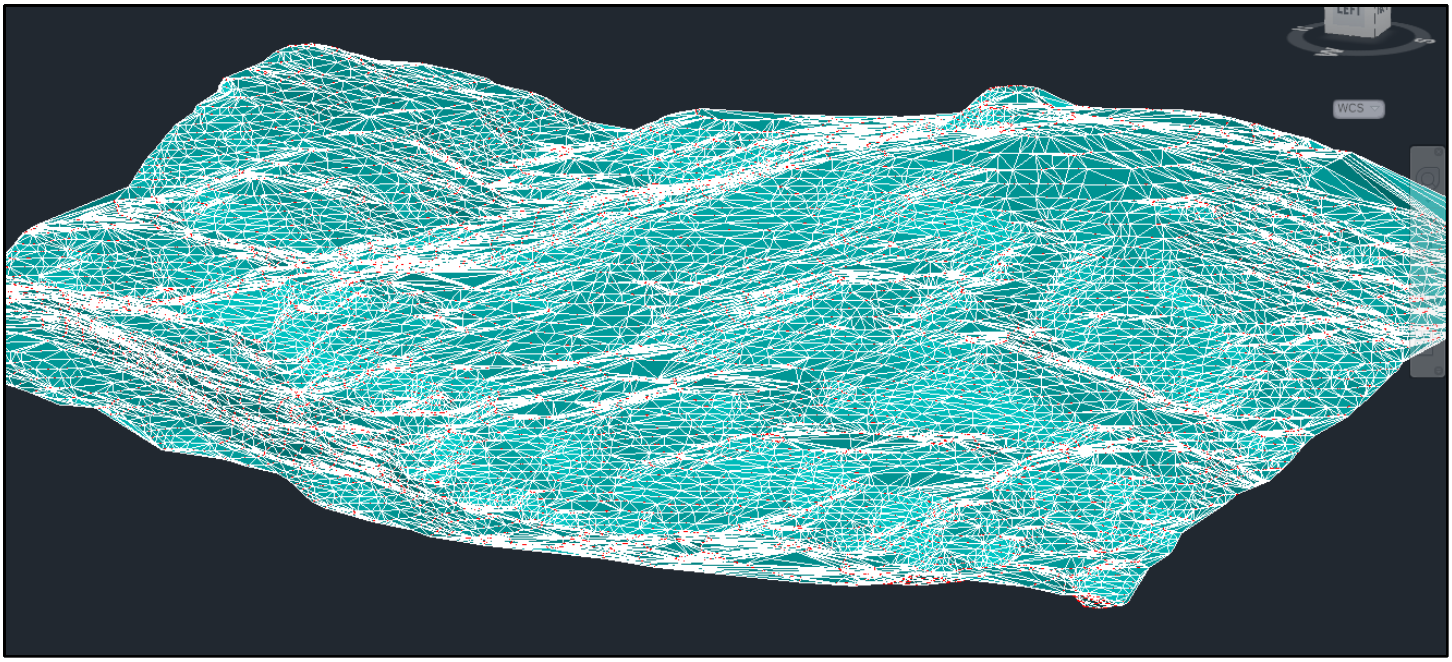


Figure 4.6. 3D topographic model converted from DroneDeploy contour data.

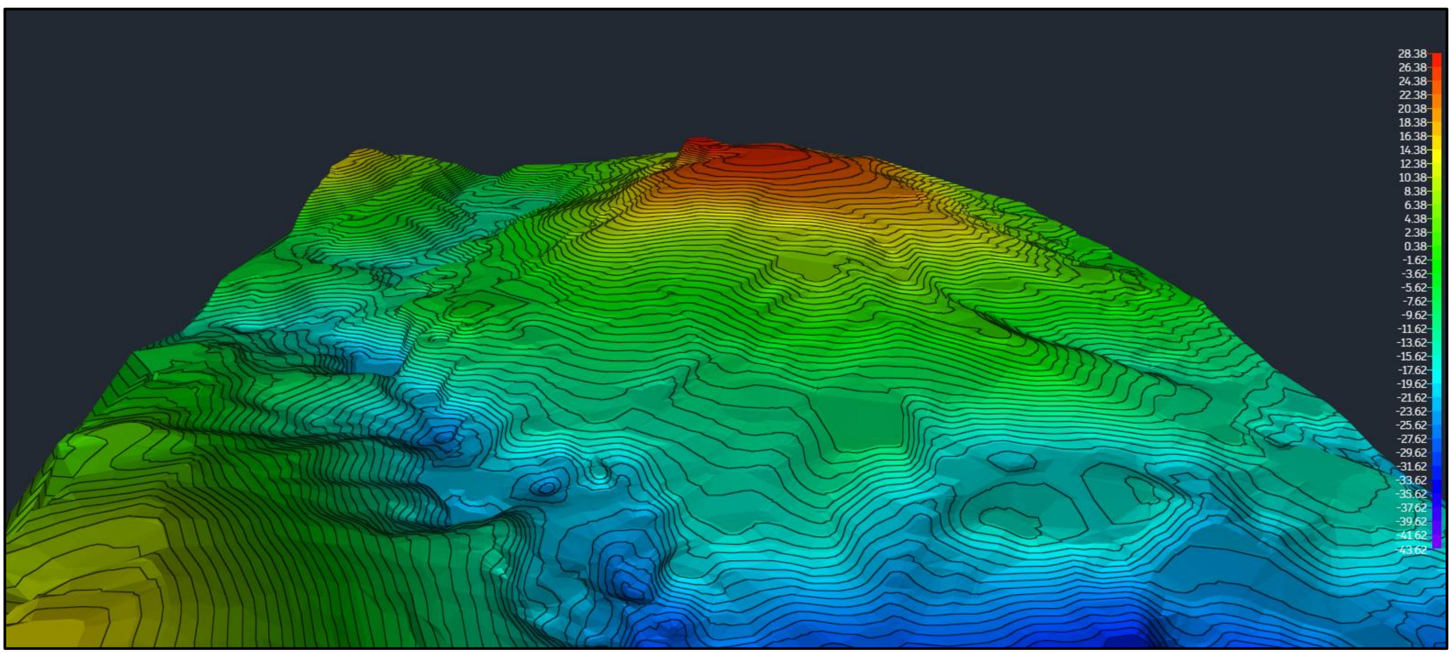


Figure 4.7. Conversion of orthomosaic into a 3D topographic model (color gradient).

Both of these existing ground models were set to become the foundation for the rest of the 3D site design. The raster overlay, similar to the 2D DroneDeploy raster file, especially helped in viewing the elevation differences and the conditioning work necessary to utilize this site for the Environmental Technology Park.

4.2. Site Components

Below is a breakdown of each site component in the PTAM from the initial iteration to the final iteration and the reasoning behind each engineering design change.

4.2.1. Transfer Center

Each site component went through an iterative design process to meet the design criteria explained in chapter 3.1.2. The transfer center was the largest and most demanding, meaning it was the first to go through this design process. The initial dimensions were 20 meters by 30 meters which ended up being the first change the team made. Knowing there needed to be five loading bays, the length was changed to 45 meters. This allowed for the three-meter loading bays to be spaced out by 3.65 meters which accommodates all industry standard trucks including the WB-50. The WB-50 trucks were indicated by black polygons in the first couple designs. The first iteration of the transfer center can be seen on the right in Figure 4.8. This included an upper and lower level for the vertical design and loading areas on either side. The height difference between the levels was five meters which allowed the trucks with a height of 4.11 meter to pull below the tipper flow above. The team added enough pavement and roadway space for the trucks to comfortably pull in and out of their respective loading areas. Figure 4.9 on the right shows the second design which included the addition of the public drop-off. This area included a lower space with four containers and an upper level for public vehicles to drive up. The design of this drop-off allowed for the containers to be pulled out following the red arrow and their contents sorted on the tipping floor of the transfer center. The loading bay area was also shaded a darker gray to highlight that this is on a level above the lower trailer parking. This road where the trailers are loaded from the top had to be increased from seven to nine meters for the trailers to be placed more comfortably. The third iteration of the transfer center seen below in Figure 4.10 had a mixture of visual and functional changes to its design. The main change was the public drop off was

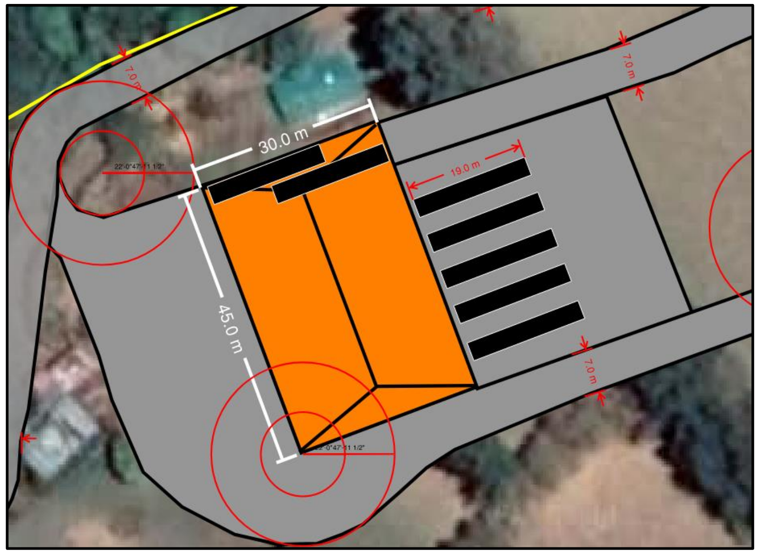


Figure 4.8. TC Iteration 1.

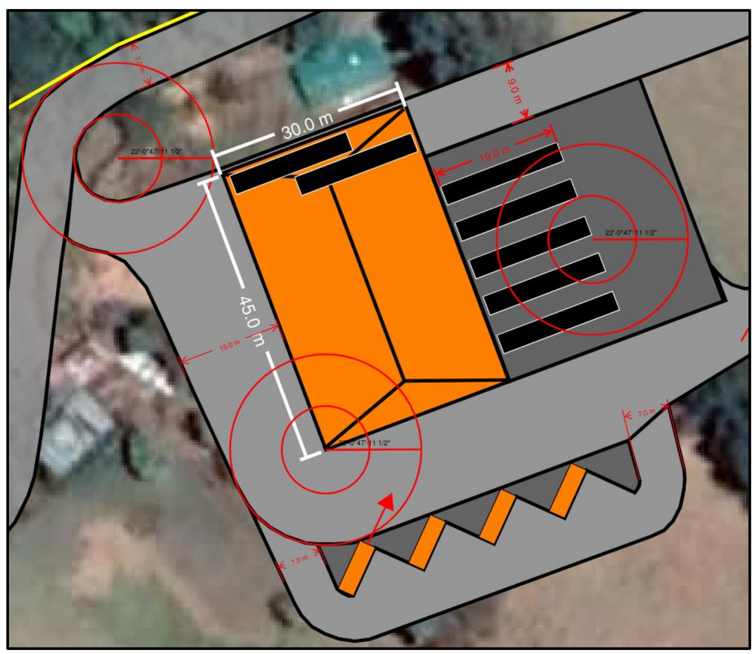


Figure 4.9. TC Iteration 2.

separated from the transfer center and placed in the front. This would allow the public vehicles a quicker more effective entrance and exit from the drop off area while also avoiding the large trucks and machinery by the transfer center. It was also determined that the contents of the containers did not need to be sorted on the tipping floor of the transfer center and were picked up by different trucks. Additionally, two larger containers and an extra container spot were built into the design. Another functional change was the ramp down from the upper level of the transfer center to the lower level to allow for a better flow of traffic. As far as visual changes, a retaining wall was added between the upper and lower levels of the transfer center to better highlight the 5-meter difference between the tipping floor and the trailer loading below. The width was also increased to 35 meters to allow for a 5-meter space between the trailers beneath the tipping floor so that they were aligned with the tipping trucks above them. The different connecting roads and terrace levels were also shaded to help paint a better picture of verticality and relationship of aspects within the transfer center and public drop off. Much of the constraints and design criteria are explained in the terms of reference from the ASADA in Appendix B. The final design of the transfer center can be seen below in Figure 4.11. This final iteration was cleaned up after the team did their best to minimize wasted space while maximizing functionality.

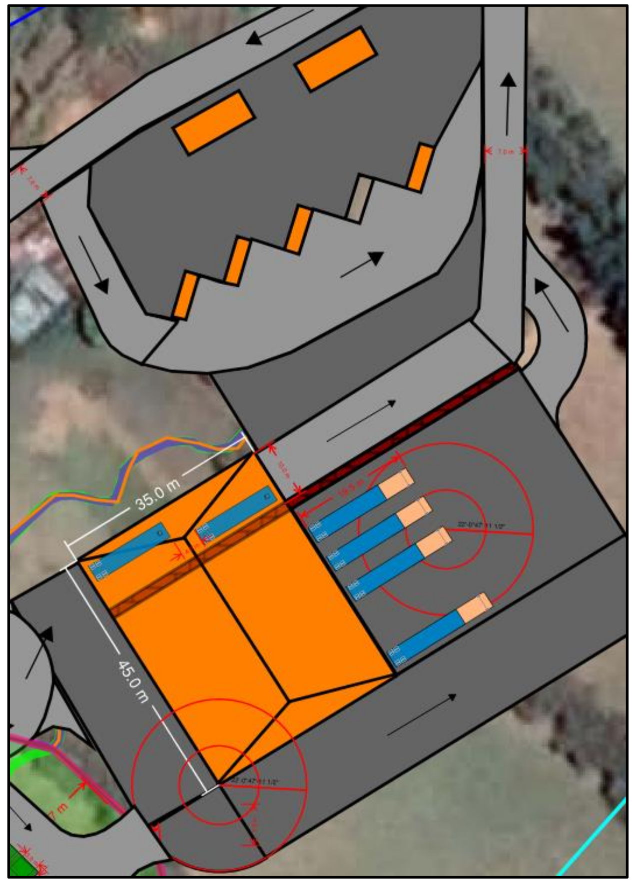


Figure 4.10. TC Iteration 3.

Figure 4.11. TC Iteration 4.

The public drop-off was moved against the side of the trailer loading drive as this would conserve valuable space on the site. This also changed the access roads and more of the pavement layout as the goal was to maintain functionality determined by previous iterations while minimizing surrounding site impact.

4.2.2. Productive Treatment Plant

The productive treatment plant was the next site component the team put through the design process. The first design seen below in Figure 4.12 was a basic design with dimensions based off the existing treatment plant owned by the ASADA. This new plant was intended to utilize the extreme terrain by creating a leveled system. Design one had the top building on the highest elevation with each corresponding building down a level to allow for easy transfer through treatment phases. There was also a drop off area which was placed next to the top-level building to allow for storage and pickup of fertilizer produced.

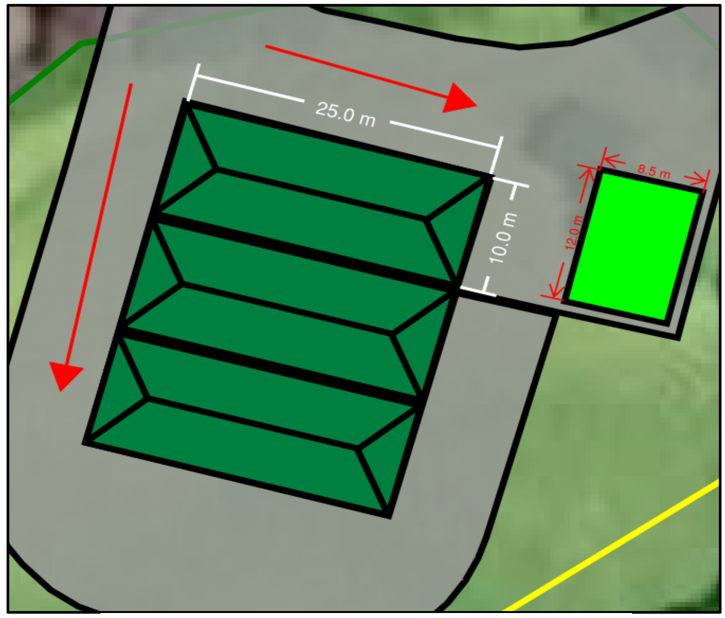


Figure 4.12. PTP Iteration 1.

The second iteration of the productive treatment plant was a more comprehensive design when the team understood more about what was required of the productive treatment plant. In this iteration, there are four levels with completely different sized buildings which can be seen in figure 4.13 on the right. The top-level building in the new design is the truck and cistern unloading area. There was a 5-meter spacing that was added between the level to allow for small trucks to drive through and assist with any transportation of materials and allow for greater mobility between each side. Throughout the phases of treatment and production it is vital that all the organics such as leaves and food stay underneath a roof which is why this top building will also serve as a mixing area. The dimensions of cistern and rough mixing areas were added in this building which is 10 meters by 20 meters. This size of building is common to the buildings on the first three levels. The next building on the level down is for the holding tank and 1st phase of the aerated static composting (ASC). We included a tank that is five

Figure 4.13. PTP Iteration 2.

meters in diameter and eight bays for the ASC that are each 2 meters by 4 meters. These bays will be where the compost is held for supplements like water to be added while porous PVC tubes pump oxygen into the piles. The third level down is the building where the second stage of ASC takes place, so the team placed another eight bays. The final level contains two plots where the final stage of the ASC happens as well as the co-digestion reactor harnessing resources from the organic waste. The reason this plot is much larger than the others is because the final stage of ASC is drying, sifting, and sorting the compost for final packaging of the fertilizer which demands a lot of space. The co-digestion as well as the treatment of liquid digestate from the ASC also require space on this terrace, which is indicated by the fifth building in the bottom left corner. These elements that are incorporated into the design are explained in Appendix B in the PTP terms of reference. The final design can be seen below in Figure 4.14 as well as the conceptual layout for each productive treatment plant tier in Figure 4.15. The only changes from the second iteration to the final was the orientation of the buildings and the space of available pavement around them as well as the addition of an entry road to the north. The design was also cleaned up to better display the measurement of each building and internal component.

Figure 4.14. PTP Iteration 3.

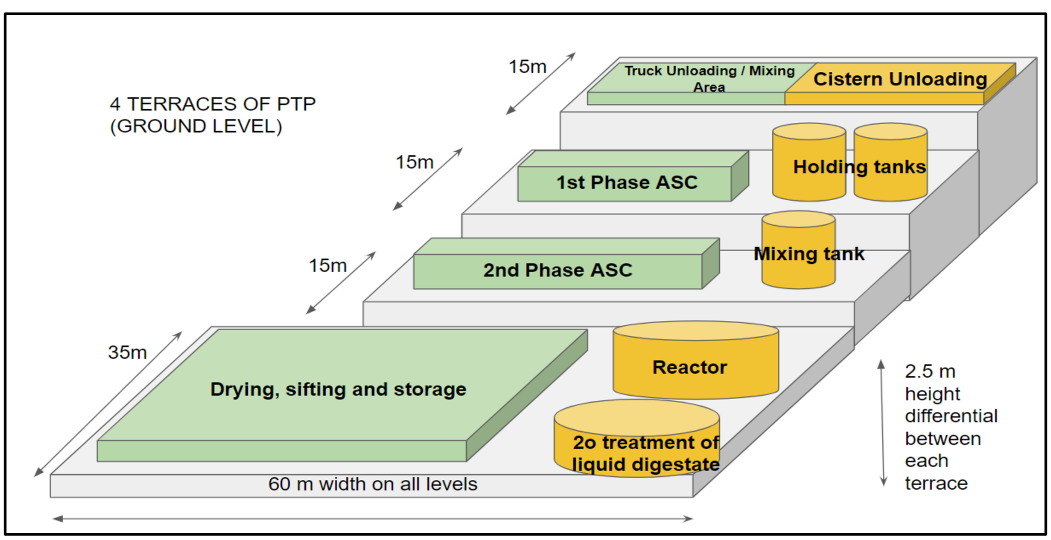


Figure 4.15. Terms of Reference for Productive Treatment Plant (Welch, 2021).

4.2.3. Wastewater Treatment Plant

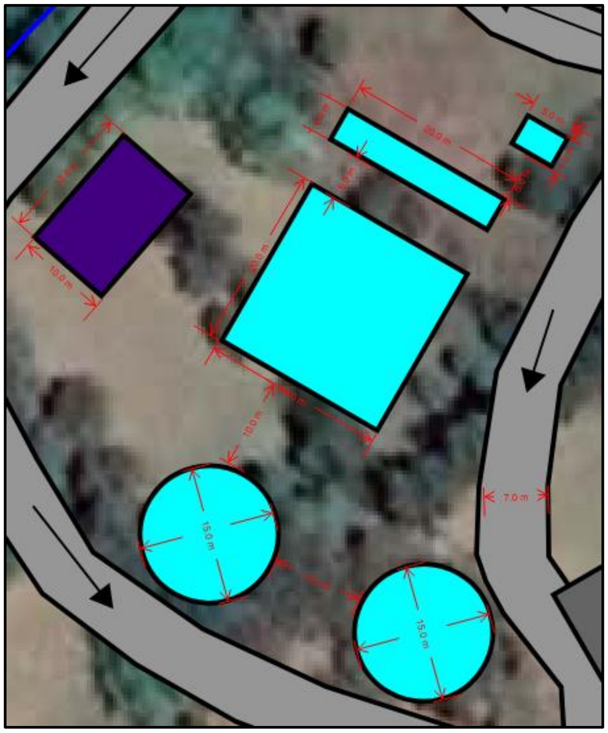


Figure 4.16. WWTP Iteration 1.

The first design of the wastewater treatment plant that the team created only had the general dimensions for the treatment train components. In this iteration, seen on the left in Figure 4.16, the components were placed in their designated ASADA territory to gain a better sense of the land and space available. All the blue polygons represented the entire wastewater treatment train including pre-treatment, primary treatment, and secondary treatment. The smallest blue shape resembles the large particle removal (pre-treatment) and is five meters by five meters. The second longer blue polygon is the fine grit sedimentation (primary treatment) which is 4 meters by 15 meters. The third and largest component is the anaerobic AFAF (secondary treatment) which is 20 meters by 20 meters. The final two circles represent that space taken by the trickling filter and the secondary settler which take up 15 meters in diameters each. All of these components can be visualized in examples from the ASADA in Appendix B. The final purple polygon represented the office space that was necessary for this area of the site. This design was then adapted once the team knew more about where the components needed to go after learning about their interactions. Surrounding pavement areas for each component were added as well as a parking lot space for the administrative offices. The treatment train was also oriented in a manner that better suited a gravity-fed interaction allowing the first component to be furthest uphill in the ASADA territory. This final design can be seen below in Figure 4.17.

Figure 4.17. WWTP Iteration 2.

4.2.4. Weigh Station and Administrative Building

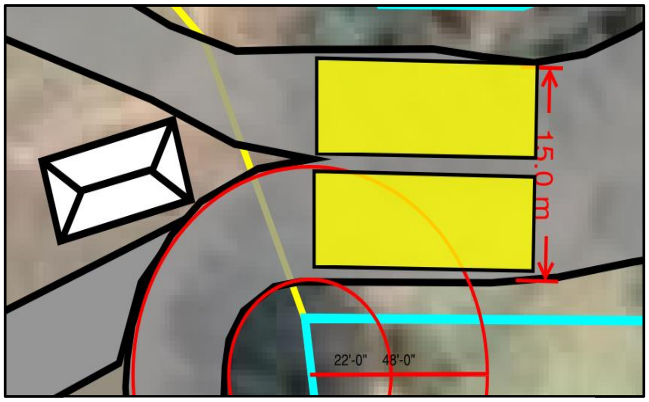


Figure 4.18. Weigh station Iteration 1.

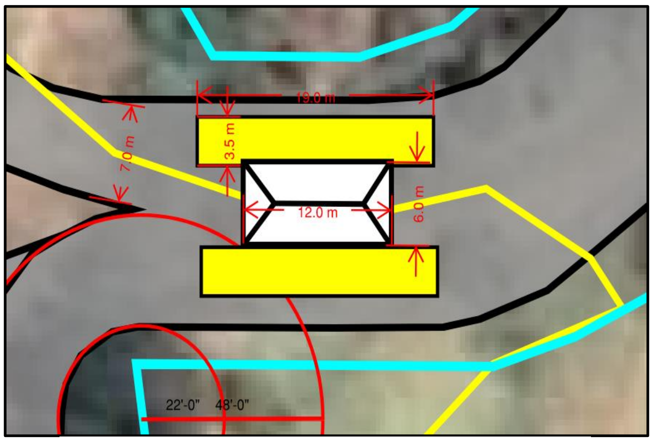


Figure 4.19. Weigh station Iteration 2.

The beginning stage of the weigh station incorporated two weighing plates, one for incoming trucks and one for outgoing trucks. The width of two of these plates fit perfectly next to each other on the entrance road as you can see in Figure 4.18 on the left. This forced the administrative building that was 12 by 6 meters to be placed further down in between the entrance and exit route. Having the building a bit further from the stations is not ideal, as the worker will need to interact with the trucks that pass through.

The next iteration of the weigh station addressed the issue of the building being too far. To accommodate the building, the weighing plate width was decreased to 3.5 meters and lengthened to 19 meters. The new dimensions of the weighing plates accounts for WB50 trucks and created enough space for the gate office to be placed between the plates. This change still made it possible to weigh the two-way traffic in and out of the site. All these changes can be seen in Figure 4.19 on the left. Moving forward the team decided that two weighing plates would not be necessary. Instead, the configuration and traffic pattern of the road was adjusted. The weigh station design allows for through traffic both ways that bypasses a singular weigh plate which accommodates any vehicles like public vehicles. They may pass the office and continue into the PTAM and leave at the same efficiency without waiting for truck traffic that is being weighed. In this design the gate office can still tend to traffic on both sides. The removal of an extra weigh plate will also help cut down on cost for the ASADA and Municipality. Figure 4.20 below shows the changes made in the third design.

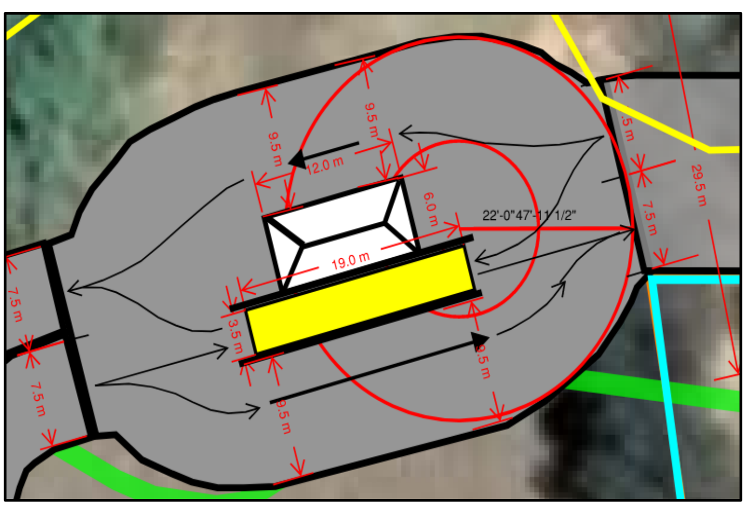


Figure 4.20. Weigh station Iteration 3.

The last weigh station design can be seen below in Figure 4.21. The only changes from the previous design to this one is the general orientation and shape. It was necessary to widen the corners of the road by the station. To be conservative the turning radius was used and followed along the edges. The orientation was also changed as we angled the station, so it was a more direct line from the plate to the roads.

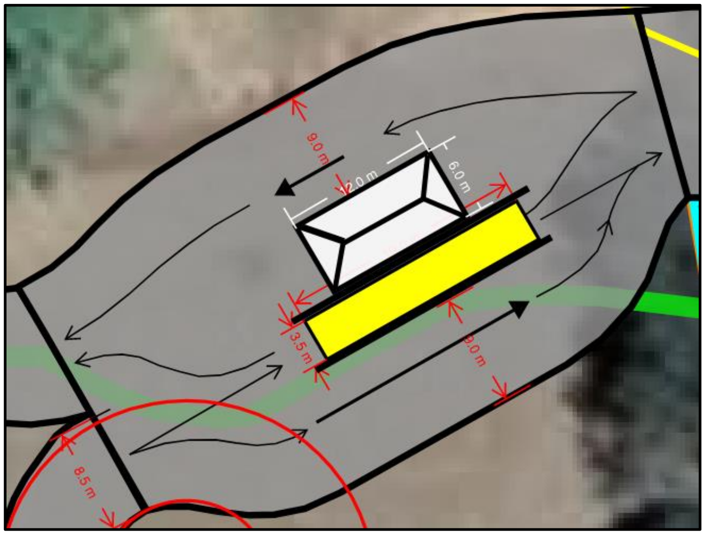


Figure 4.21. Weigh station Iteration 4.

4.2.5. Office Buildings and Workshops

Additional site components were added after most of the site was designed which were administrative offices and workshops. The space within the wastewater treatment plant needed the admin offices and the workshops were added near the public drop-off and transfer center. These spaces would provide working space for the employees of both the ASADA and Municipality. It was determined that the sizes for the workshop and administrative offices could be the same dimensions of 10 meters by 15 meters. The only other 2D site requirements for these buildings were the parking lot space outside.

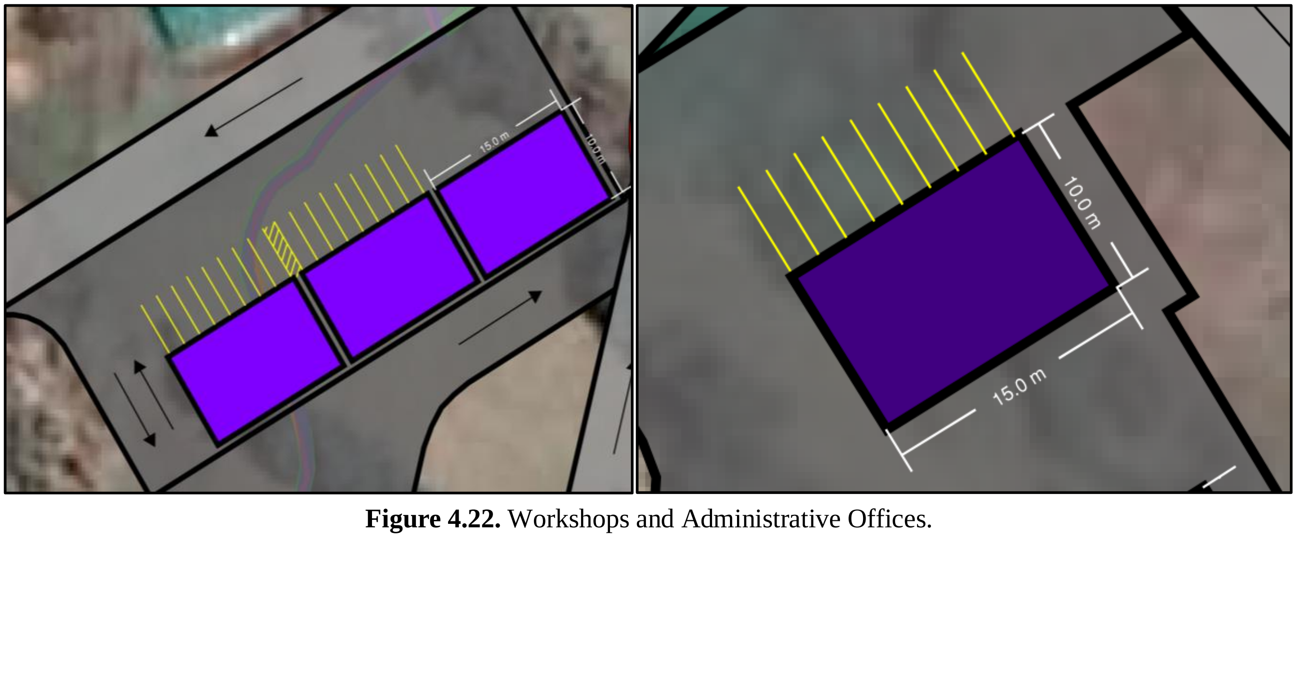


Figure 4.22. Workshops and Administrative Offices.

4.3. Layouts and Elevations

While creating different 2D site designs the information gathered while identifying components was essential. The first component that was assigned a location was the transfer center. Based on the raster photo from DroneDeploy the site slopes downhill from south to north. Due to the need for a tipping floor at a lower elevation, it was decided to have the tipping floor on the north side of the building to align with the existing topography. By doing so the existing topography of the site was used in favor of the building design. The loading zone was determined to go on the east side of the building. On the east side of the building there is more space for WB50 trucks to maneuver themselves as there was no plan for having another building east of the transfer center. As the orientation for building was determined the team tried giving it different locations on the site. The first proposed location was towards the front of the site with the public drop off center right behind it. Another location that was tried was at the back of the site near a steep drop off pictured in Figure 4.23. As a team it was decided that having this component on the back of the site would benefit the overall flow of the site. Placing the transfer center near the steep drop allows for less grading of the site. If the upper level of the transfer center was on this incline somewhere, the ground level would have a natural lower elevation to work with.

Figure 4.23. Future location of Transfer Center.

The public drop off center began by being attached to the far side of the transfer center. After working with the site for a few weeks it became apparent that having the public drop off area at the front of the site, despite the transfer center being at the back, would be best. By moving the public drop off to the front of the site it provides easier access for the community when they need to dump waste and it moved the transfer center further from the site entrance.

The productive treatment plant had a plot of land assigned to it at the southwestern corner of the site. This made the placement very simple and involved making sure the determined internal components fit within its designated plot. The major factor that influenced the final design was the environmental impacts that the productive treatment plant may have. Due to the nature of producing fertilizer through aerated static composting it produces a large smell that can travel to nearby land. This along with the bad smelling liquid waste produced from the composting meant that the PTP had to be moved as far as possible from the southwest site boundary. Figure 4.24 below shows the rotation of the final iteration of the PTP which the team incorporated in an active attempt to be considerate for neighbors and minimize impact on surrounding land.

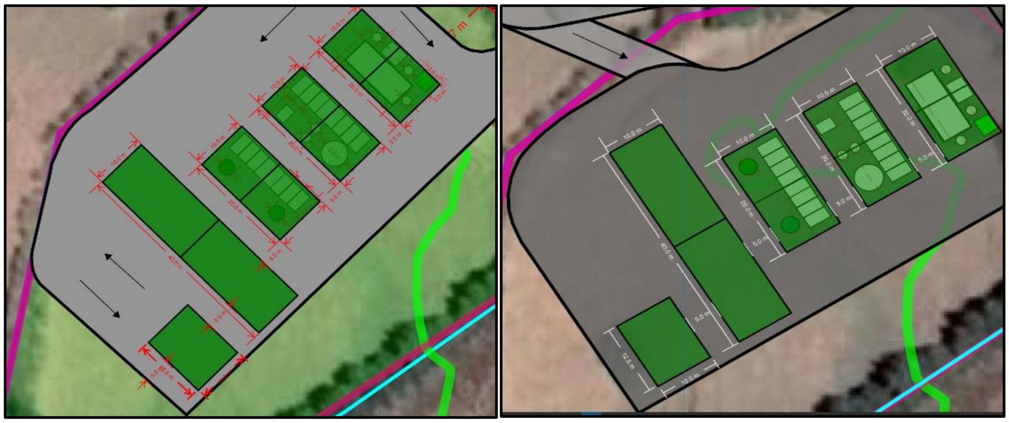


Figure 4.24. Rotation of the PTP away from southwestern property boundary.

While designing the wastewater treatment plant, orientation was more important than dimensions. For this specific component, the dimensions were gathered by Justin Welch and another group of UTN students in Costa Rica. He was able to use existing technologies in communities with a similar size to Monteverde to estimate dimensions. This resulted in determining a pretreatment structure that will be a 5-meter cube shape, the sedimentation tank being 15 by 4 by 2 meters, an anaerobic reactor 20 by 20 by 5 meters, a 10-meter radius filter with a 2.5-meter height, and a settling tank with a 5-meter radius and 2.5-meter height. As mentioned, orientation was more important and that is where more time was devoted. For this step the raster was utilized again. The team decided the northwest corner of the site would be suitable for this technology. This area of the site had a much less gradual slope in comparison to most areas. Across most of the designated ASADA site territory the grade averaged around 16%. Through the design process the orientation of the PTAR changed ever so slightly. Figure 4.24 shows the general shape held by the PTAR through the design process. The northernmost building is the first step of the treatment process and the flow of the buildings down site goes through the rest of the steps. After the order of features in the treatment train was decided, the spacing between the structures was determined. The treatment structures needed to be relatively close to each other to allow for a gravity fed system. The first three structures are spaced at 5 meters, while the filter and settling tank are 10 meters away from each other and the anaerobic reactor.

4.4. Access Roads

The first step in designing the site access roads was the entrance to the site. This needed to be wide and easily traversed by large vehicles as it would serve both the waste vehicles and the public. It was made in the final design to be 15 meters wide and traverse over the riverbed into the site. The bridge details were not elaborated on by the team as it did not fall within the scope of the goals, yet it is important to understand that its construction will be vital for the site development. After the entrance road was designed, the internal access roads were the last step of the 2D design. The road system is a one-way loop around the site that accesses all the different components. Throughout the design process and as buildings were moved the road went through various changes. The first design was purely based on connecting the site features and handling the accessibility demands of the WB-50 truck. Figure 4.25 below shows the first iteration of the road design without the buildings. The team first thought to run this access road at the very edge of the constraining boundary and split the ASADA and Municipal territory on site. This was meant to save as much space as possible for the buildings. The only turn for concern was the 180-degree turn back into the TC trailer loading area.

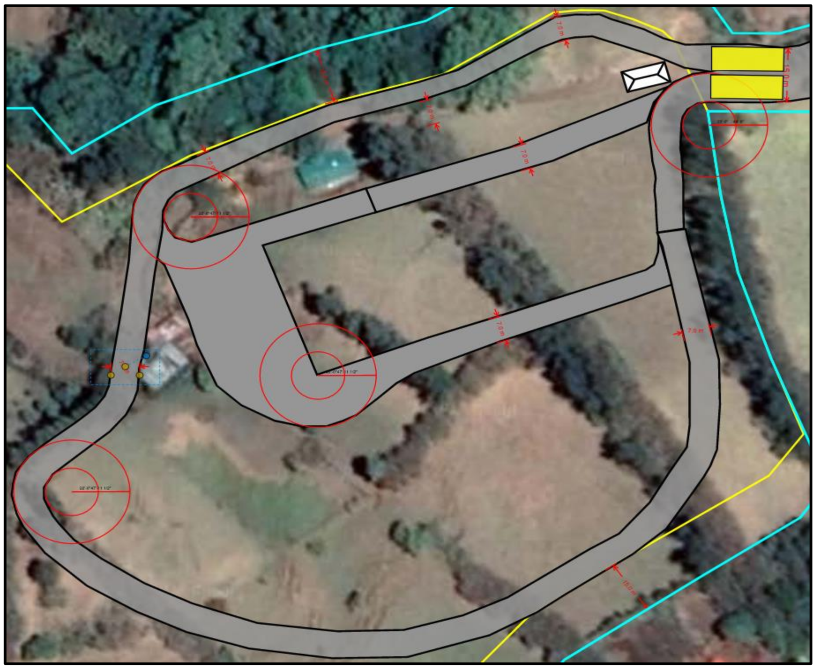


Figure 4.25. Road design Iteration 1.

After looking at the functionality of the roadways the team realized some changes that needed to be made. One flaw was the road along the Eastern boundary that was going directly down the steep hill. This was a disadvantage as large WB-50 trucks, especially those carrying heavy loads, would struggle to perform on the intense grade. The second iteration of the road system including such changes can be seen below in Figure 4.26.

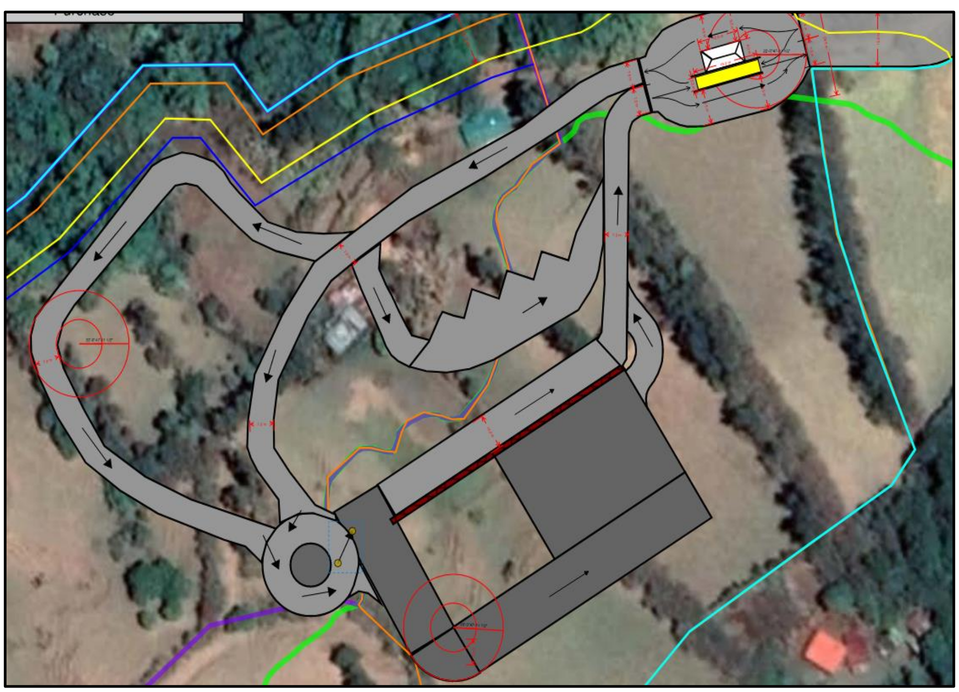


Figure 4.26. Road design Iteration 2.

In this design the road changed substantially. The road that followed the southern border was consolidated into the transfer center area clearing up more space for it to be moved down. This allowed for the access of this component to be less intense with no turn greater than 90 degrees. At this stage the access road for the wastewater treatment plant was added that looped around the ASADA buildable area. This new road needed to rejoin with the original road while also allowing access to the southwestern corner of the site where the PTP would be placed so a traffic circle was added. This allowed trucks from either road to enter the PTP or transfer center without difficulty. The last notable change is that the road on the east of the property was removed and another exit from the transfer center was added that cut across the steep hill towards the entrance. This would overall help decrease the steep grade and ease the demand on the WB-50 trucks. Eventually the team was able to produce a final road design after all the other site components were finalized which can be seen below in Figure 4.27.

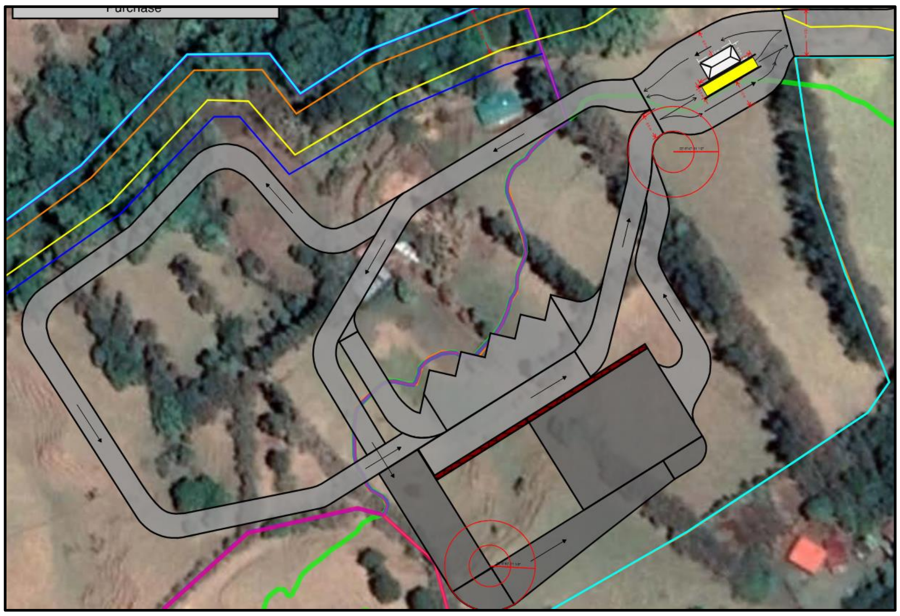


Figure 4.27. Finalized access road design.

The traffic circle was removed as the western WWTP road was angled differently allowing for an intersection. The flow of the road indicated by the arrows on the road show that trucks can take different routes to access different parts of the PTAM. The road exiting the transfer center also needed to be adjusted to join the main exit road further down, so it had more distance to meet the lower elevation. From previous designs to this one, road with unnecessary curves were cleaned up and turned into straight roads with few turns. This final design is the most functional of the team's designs and is also the most aesthetic which does play a factor.

4.5. Final 2D Design

Below in Figure 4.28 is the final iteration of the 2D site design.

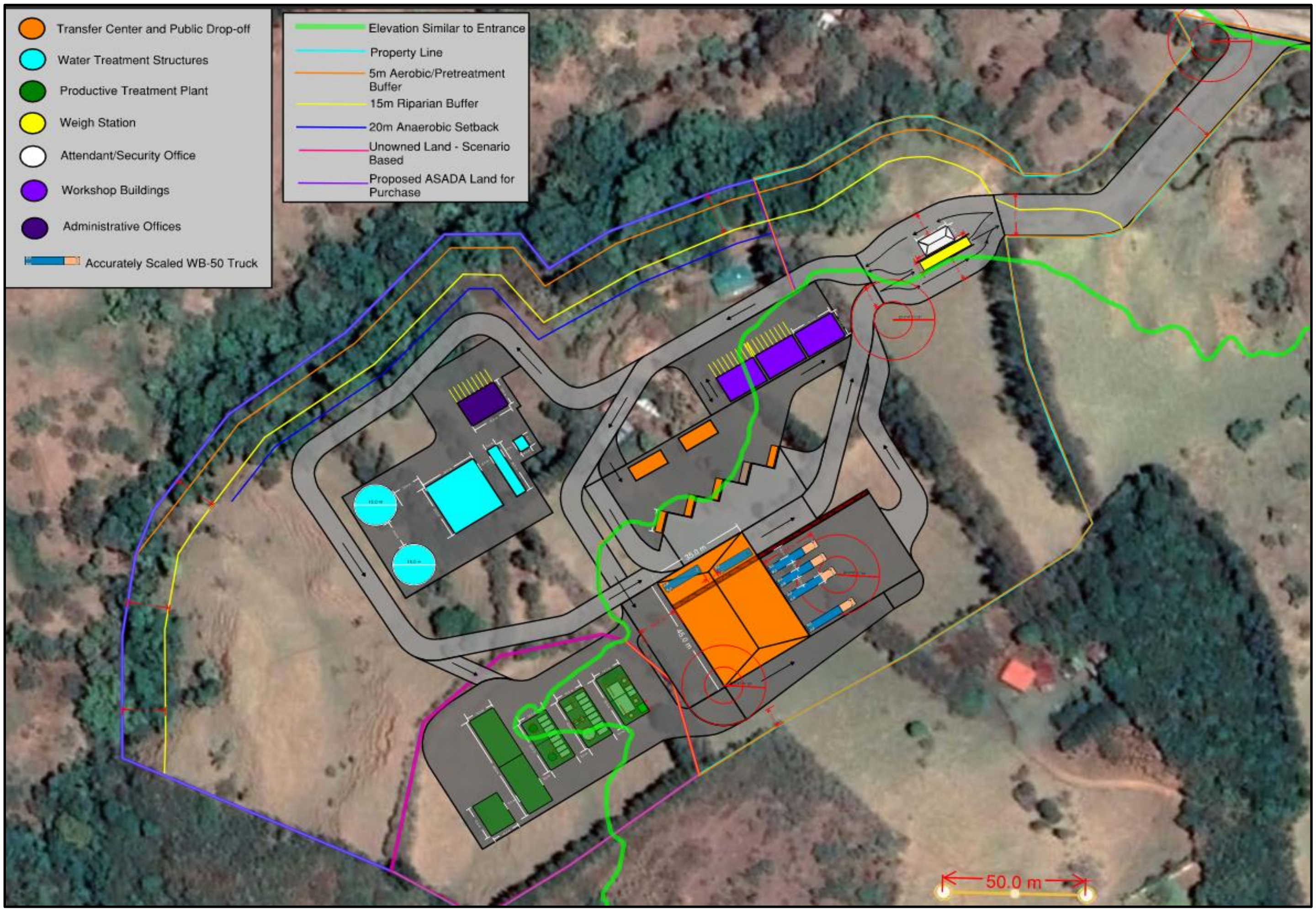


Figure 4.28. Final 2D site design using Bluebeam Revu.

This final 2D design combines all the best ideas from the team's previous iterations into a clean and functional design. The transfer center was locked into its position at the southern edge of the site, near the steep drop-off. The road that runs behind the transfer center to access the loading bays was tapered from 10 meters to 7 meters. This was a small, but necessary change as the thinning of the road allows for a barrier of trees to be planted prior to construction. The trees will act as a natural buffer for neighbors, blocking the view of the PTAM as well as the smell. There was also extra space left on the eastern site boundary that could be used for future development for the Municipality. The area on the western side was similarly left empty due to the need for erosion control. It could serve as a place to put extra structural fill from the excavations necessary to level the building plots and surrounding infrastructure. At this point the team felt comfortable that the final 2D site design produced from an iterative design process would serve as a sufficient starting point for all the 3D modeling and engineering left to perform.

4.6. Final 3D Designs and Walkthroughs

Below in Figure 4.29 and Figure 4.30 are the finalized 3D renderings and floor plan of the weigh station respectively that were created in the Autodesk Revit software. These were customized to suit the foreseen ASADA and Municipalities needs and could be used as powerful visualization tools as the project moves further into the preliminary construction phase. The weigh station has all the functionality such as access doors on both sides to attend two-way traffic and a bathroom to serve a full-time gate attendant.

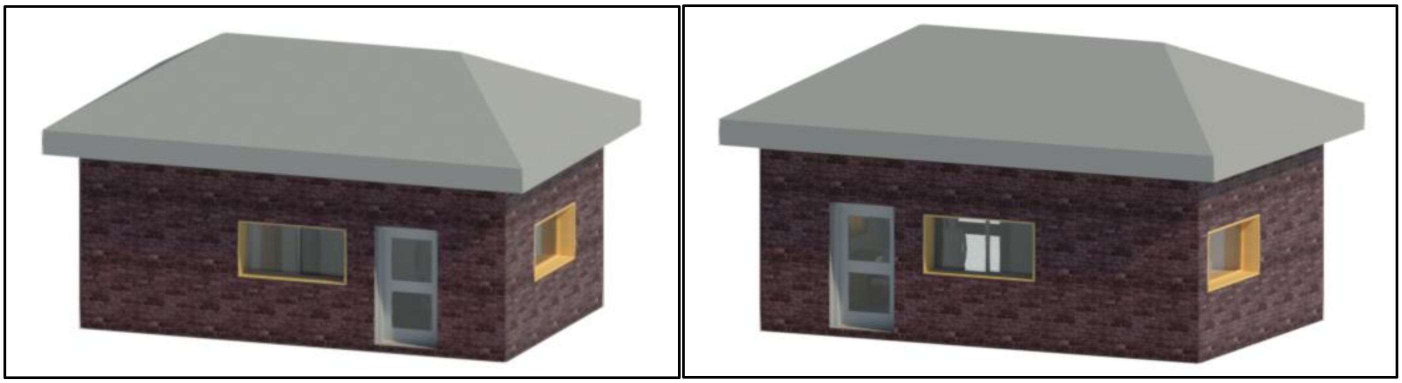


Figure 4.29. Final 3D weigh station design using Revit.

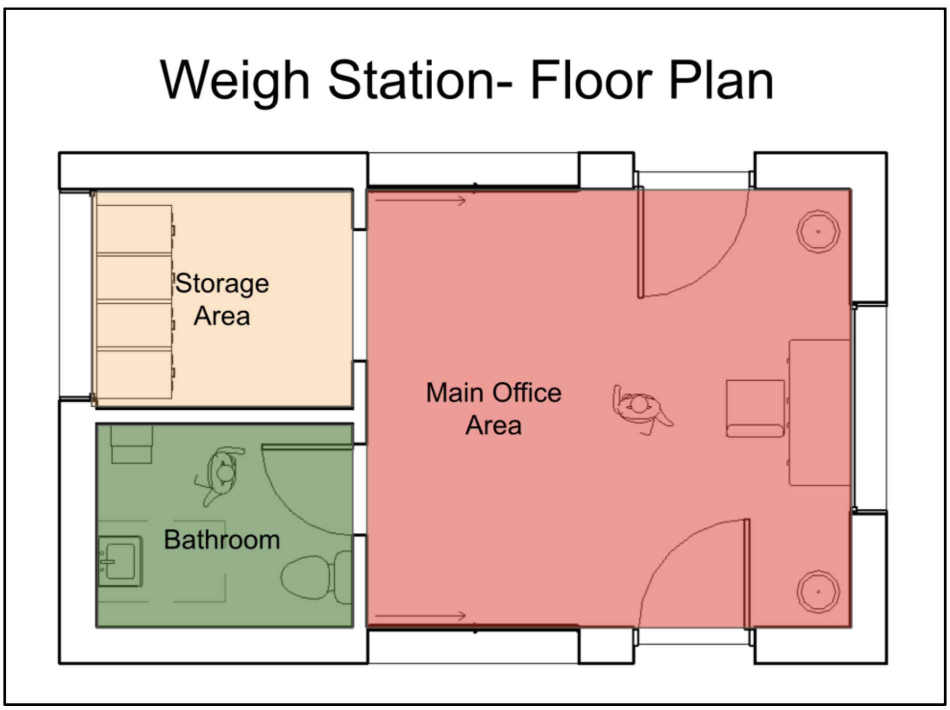


Figure 4.30. Weigh station office floor plan.

The final iterations of the Admin Office are seen below in Figure 4.31 as a exterior 3D model and in Figure 4.32 as a floor plan. These serve as renderings for the Workshops as well since these buildings have the same exterior dimensions and for the purpose of this project the workshops were left empty (to be populated in the future when their use becomes clear). Although they have very different needs, the offices have a lot of requirements for what needed to be included. The final dimensions were 10 meters by 15 meters which

provided plenty of space for the inclusion of two offices, a reception area, a kitchen, and a conference room for ASADA clients and internal meetings. A walkthrough of this Admin Office developed in Revit can be found at the following link (can be copy and pasted into a browser):
https://drive.google.com/file/d/1mRP2JSBSRBJUBsVBOMAx3Wm5hntkrGAc/view?usp=sharing

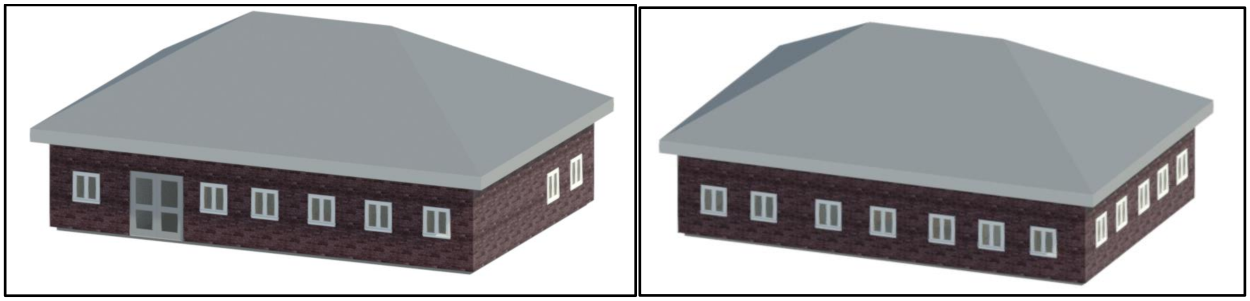


Figure 4.31. Final 3D Admin Office design using Revit.

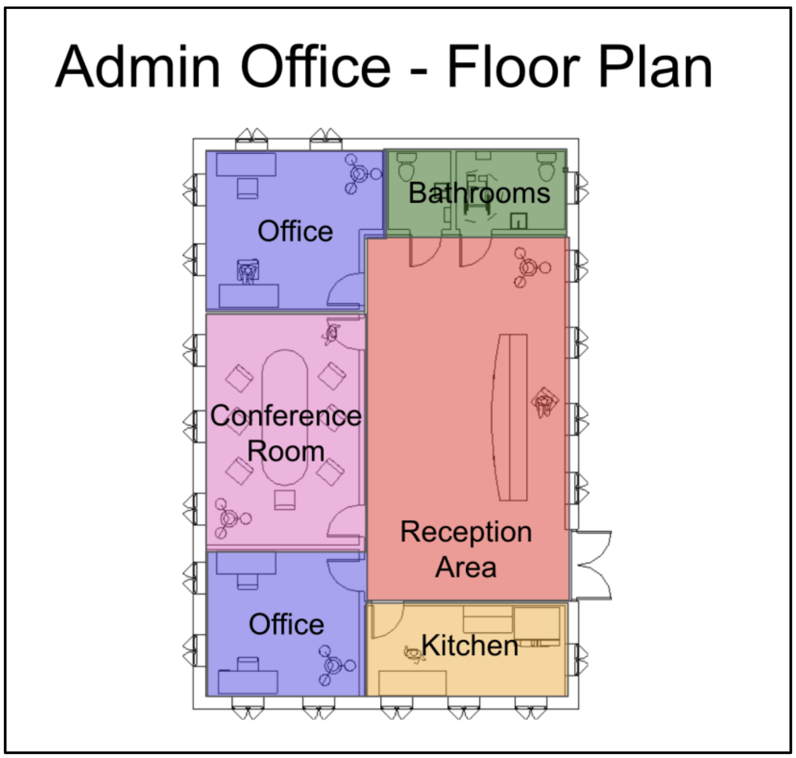


Figure 4.32. Administrative Office floor plan.

Below in Figure 4.33 is the 3D external views of proposed transfer center. To be conservative the team decided 35 meters of length from the tipping floor to the end of the building would be sufficient. The height variation between the levels also needed to be determined. The height of the WB50 truck (4.11 meters) was used to determine the height of the transfer center tipping floor height. The team decided that 5 meters would be conservative and still allow for any other future structural or architectural components to be added beneath the tipping floor, such as beams or lights. The height of the roof on the main floor also needed to be determined. Since the main floor of the transfer center would be used for loading as well as vehicle storage, the ceiling needed to be large enough to allow for normal operations to occur. With the backhoe being the biggest machinery that needed to be stored in the transfer center at 3.91 meters tall, an entrance height of 4 meters was sufficient.

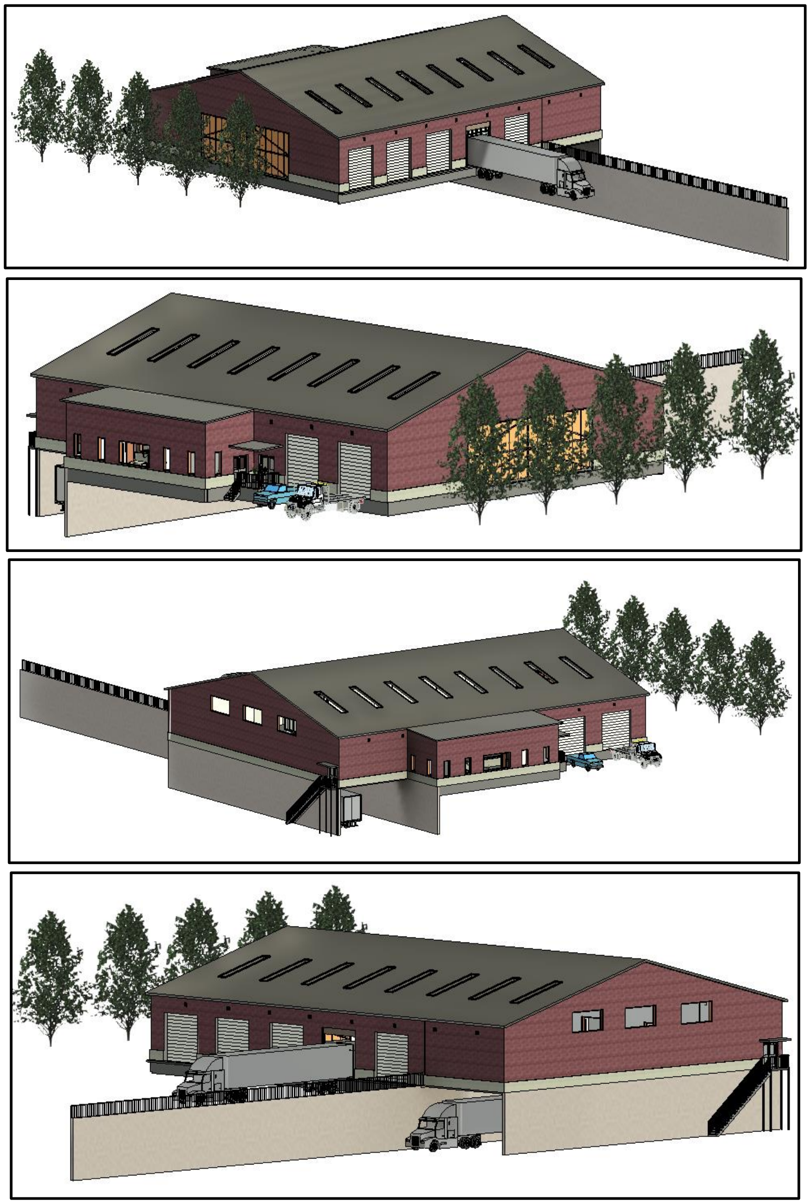


Figure 4.33. Final 3D Transfer Center design using Revit.

During the transition between the 2D and 3D it became evident that an office space, break room, bathrooms, and a small kitchen for the employees was needed. It made the most sense to put an addition on the West side of the building as there were only two loading bays. To size this addition the team needed to determine the buildable area. To do this the bounds that the building could be within were found and the team calculated that the maximum area that the addition could be 7 by 18 meters. To be conservative and allow for larger vehicles to use the road in the future it was decided that the building should extend 6m out instead of the allowable 7m. Therefore, the final dimensions of the addition were 6 by 18 meters. A walkthrough of the Transfer center can be seen at the following link (Interior renderings images in Appendix C): https://drive.google.com/file/d/1Io5ibVB73Xl3zcXW7frgzaLp9Srvn58D/view?usp=sharing

Below in Figure 4.34 the floor plan of the transfer center with all internal components can be seen in detail. The current allocation of the space in this floor plan demonstrates the versatility of its design.

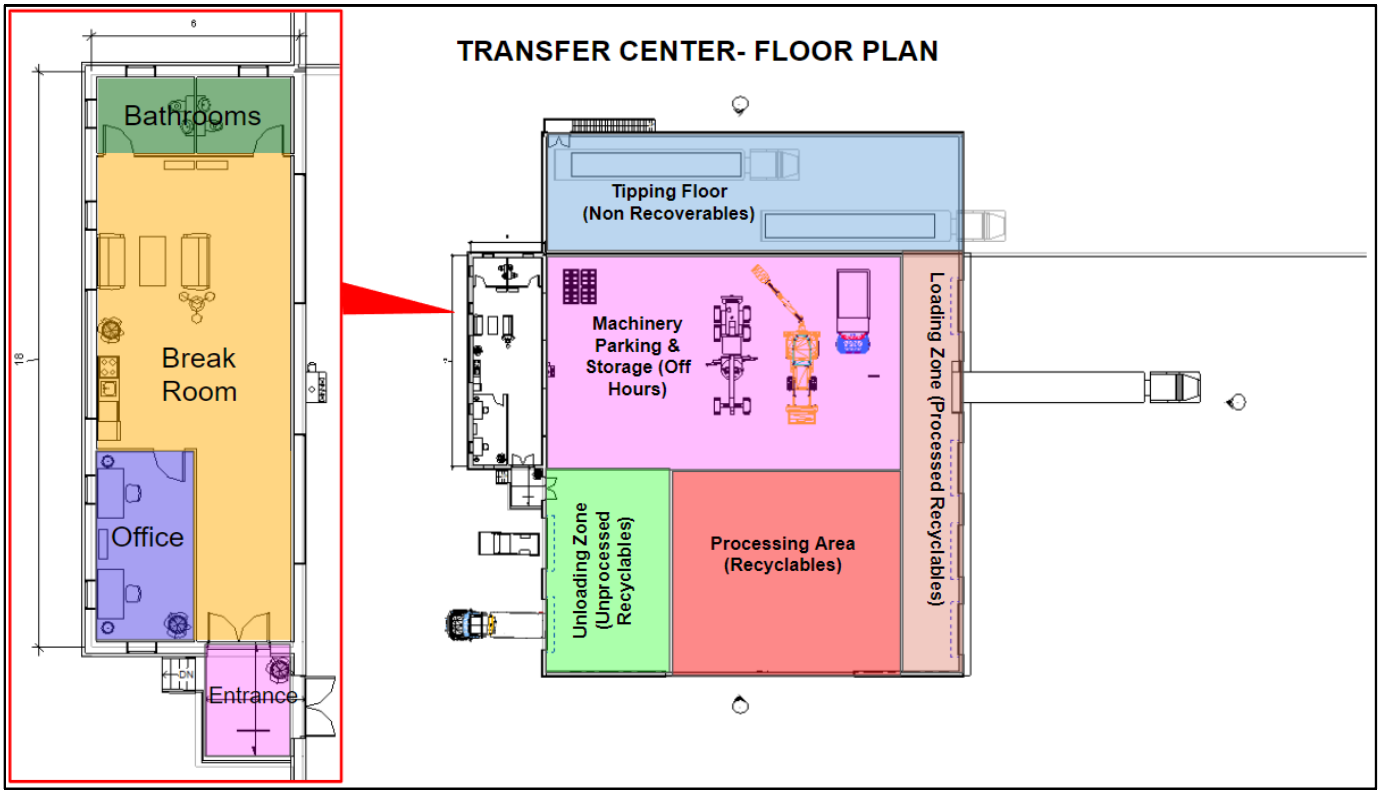


Figure 4.34. Transfer Center Floor Plan.

Another major result of the 3D site design efforts was the conceptual earthwork model produced from the grading optimization. This showcased total quantities of cut and fill while also providing a visualization of the work necessary to condition the site for construction. Figure 4.35 and Figure 4.36 show this conceptual grading optimization and resulting calculation in an elevation and aerial view respectively.

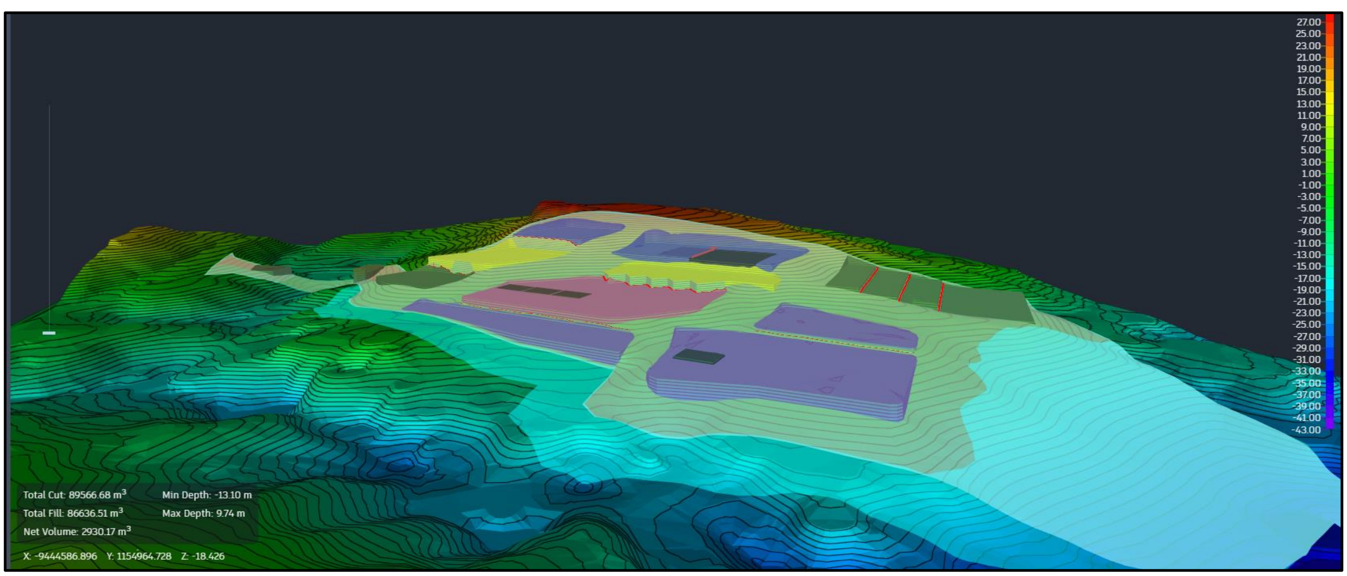


Figure 4.35. Autodesk Civil 3D grading optimization.

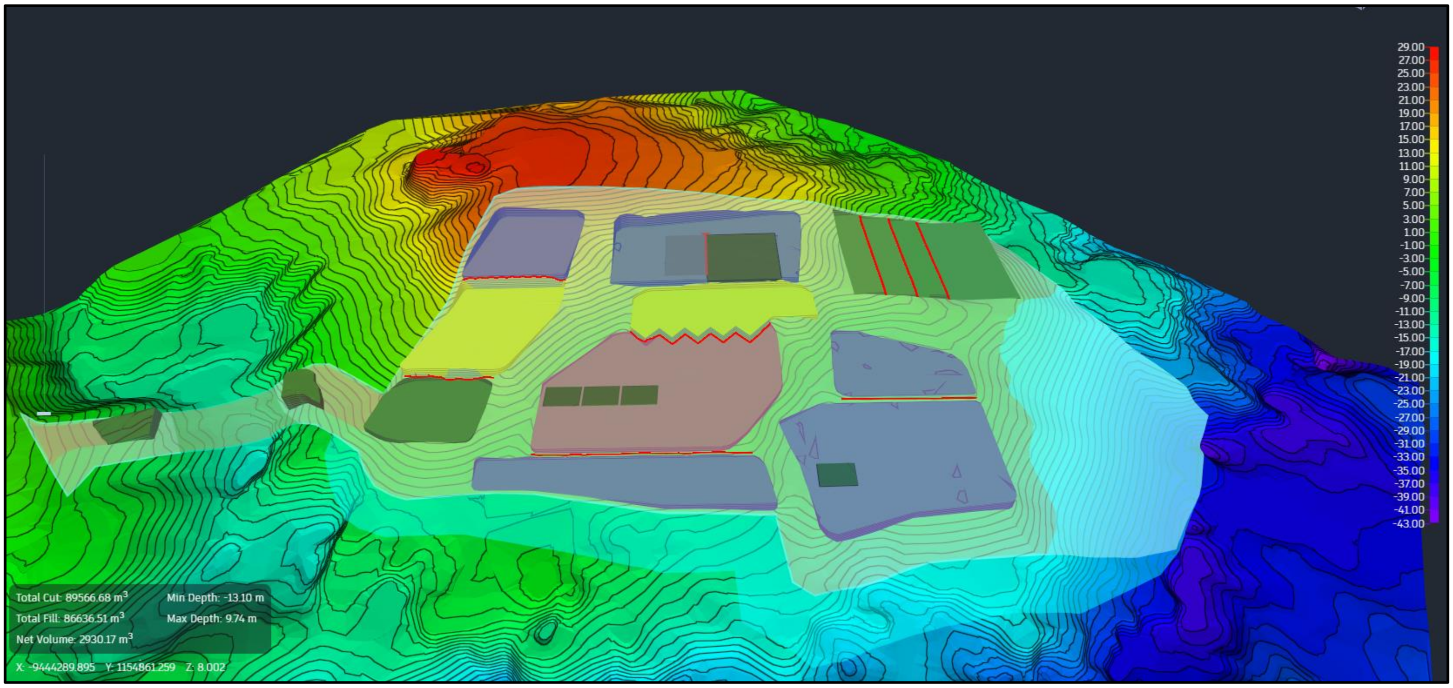


Figure 4.36. Autodesk Civil 3D grading optimization.

In this conceptual optimization the terraces to be graded into the site can be seen. These will ultimately support the building plots for all components of the PTAM. The necessary retaining walls to arrive at this design can also be seen in the model which will be discussed later as one of the major limitations. The exact quantities of the earthwork to achieve the resulting models above can be seen in Figure 4.37 below. These quantities are another limitation that will make preparing the site for construction challenging as moving earth on-site is expensive as well as the machinery required to accomplish it.

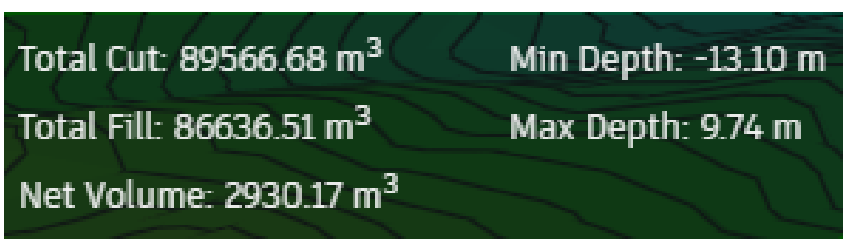


Figure 4.37. Quantities to balance the site per the grading optimization calculations.

To arrive at these quantities the calculation required user input on the grading zones. With this feature, the team input maximum grades of 25% throughout the entire site to ensure the area that wasn't part of the design would sustain erosion as well as be accessible by maintenance machinery. The optimal final elevations were also determined for the building plots and terraces. Since most of the levels were tied to one another, the higher they got placed the more fill would be necessary and vice versa the lower they were placed the more cut. In this grading optimization it was determined the Transfer Center would be at 10 meters, the lower level of the transfer center and public drop-off would be at 5 meters, and the lowest level with the bottom of public drop-off and workshops would be at 2 meters. These were all tied together and needed to have the given elevation differences to function. As a reminder these elevation values are in relation to the public road at the entrance of the site which is considered 0 meters. The productive treatment plant terraces had a similar relationship with each level 2.5 meters below the other. This placed the top level of the PTP at 2.5 meters, the second level down at 0 meters, and so on. The wastewater treatment needed a difference of 0.5 meters between terrace which placed the top level at -5 meters to accommodate the much lower elevation in the ASADA territory. The final platform that needed elevation was the weigh station which was placed at a height of zero meters to match the public road. The model also shows the land that was formed up until the riverbed where the bridge would be placed across the gap. These bridge foundation terraces were placed at -1 meter and would be tied into that level of existing ground on site. This all together resulted in an elevation difference of 16.5 meters in just the terraces alone. The 3D model that resulted from the implementation of these terrace elevations onto the existing ground can be seen in Figure 4.38 below.

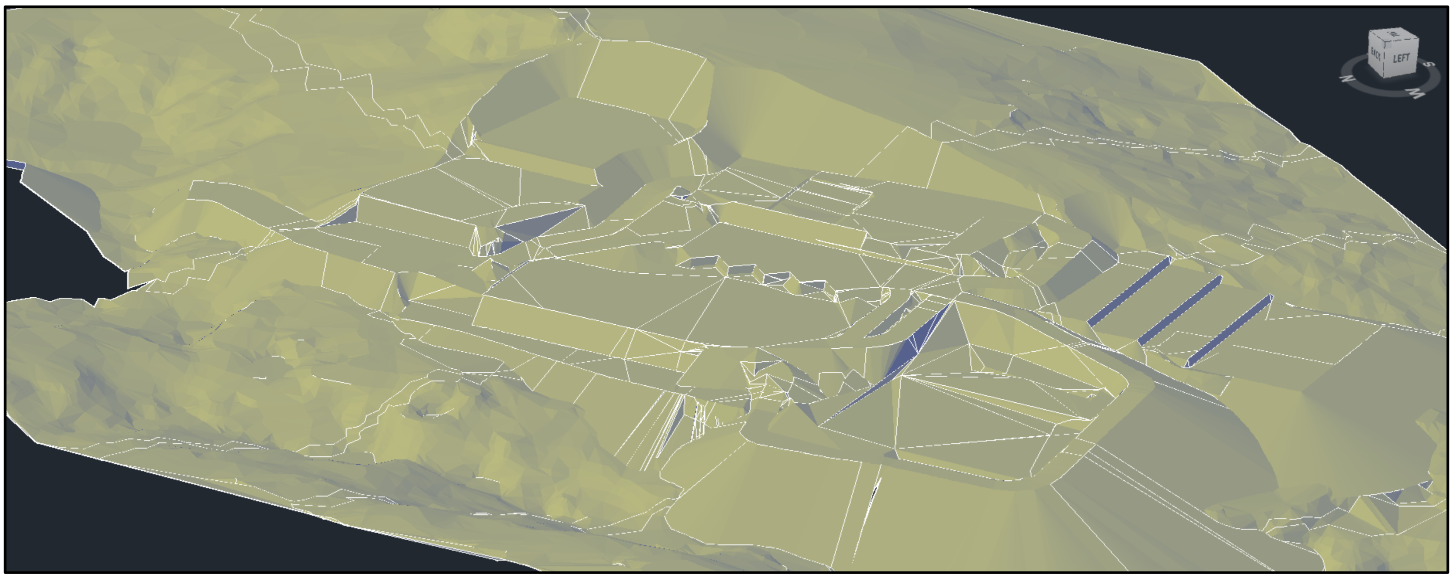


Figure 4.38. Surface model of the proposed grades created in Autodesk Civil 3D.

This model having the proposed grades physically attached to the existing ground surface gives a much better understanding of the efforts necessary to condition the site for construction. In some areas the intended 25% grading had to be increased to 30% up to 50% in the worst cases due to the property boundary.

5. Conclusion

This chapter will discuss any limitations faced throughout the project and the team's recommendation for the project moving forward.

5.1. Limitations

Throughout this project there were a few limitations the team encountered. One of the largest constraints was the time allotted for this project. The team had high standards for the work they sought to accomplish but with several technical issues both in Costa Rica and at home, time was quickly used up. The team quickly learned how to balance sponsor meetings, advisor check-ins, technical work, and writing the report. Even with adaption for the fast pace, the team agreed more time, or an altered scope of work would have served to benefit this project. However, this provided an unparalleled learning experience for the team in that the real world is often fast paced and there will be countless unexpected obstacles in any career. Learning to deal with these as they appear and still give a best effort while facing these challenges is an important lesson learned.

Another limitation the team felt, was budget constraints of the project. Prior to the start of the project the team determined that a subsurface investigation would be a beneficial data set and should be done before any construction was started. Unfortunately, the ASADA did not feel comfortable moving forward with this process, as it is quite expensive. This greatly limited the quantitative data, as the soil data could be used to assess the buildability of the site and help determine the engineering properties of soil when designing the site components. While limited in this aspect by economics, the team adapted and made assumptions instead that the site would be stripped of a meter of topsoil organics and there was enough suitable structural fill beneath to complete the earthwork requirements.

Additionally, the software presented the team with limitations throughout the project. A 3D optimized grading plan was able to be made with terraces and building pads, but due to the nature of how it was constructed that file could not be converted to a usable RVT file. This was an important median step of the project where all the site components that were made in Revit were to be placed on the 3D earthwork model. This caused a substantial delay in the project. Unfortunately, technical support was not available for use with a student license. Instead, a workaround was used where each graded item was layered onto the existing ground in a new surface. This allowed the ground to be manipulated, but it created a file that was not usable due to the nested surfaces. Instead, the export needed to be a single, clean surface. Unfortunately, the team could not come up with a solution to this problem in time. One of the main reasons Civil 3D proved to be so hard to use for construction site grading is because it was created to grade highways. While the construction industry still uses it to grade sites quite often, these extreme slope and proximity of site components made it challenging for the software to compute. Usually, a site to be graded has a much more gradual slope and which the program can easily connect the feature lines to the existing ground. The complex stacking of site pads and resembling a site after it is fully conditioned was too difficult of a process. Potential solutions to these issues would take more time than the project had allotted with one being creating the retaining walls as "corridor profiles", then re-grading the surrounding terraces to the existing ground. Although the team was unable to produce a graded site with 3D renderings of the site components as hoped, the ASADA can still use this as a tool to show the required cuts and fills for a tiered system and help convey their vision for the PTAM.

The final limitation pertains to the feasibility of the site design. The current design has an abundance of retaining walls. To grade the site many areas had a slope over 33%, which is the maximum allowable slope before a retaining wall is needed (Reid, 2022). Aside from the fact that this many retaining walls will be quite expensive, the constructability in the short term does not seem feasible with the limited equipment, materials, and labor that is required. For example, the retaining wall below the tipping floor of the transfer center requires a 5-meter height and a length of over 80 meters. A retaining wall this large would need extensive reinforcements that may or may not be accessible in Monteverde, especially considering the accessibility of the site and limited construction equipment available.

5.2. Recommendations

Below is the team's final recommendation for the Environmental Technology Park. The team took into consideration much of the limitations and constraints of this project to produce this result within the allotted timeframe.

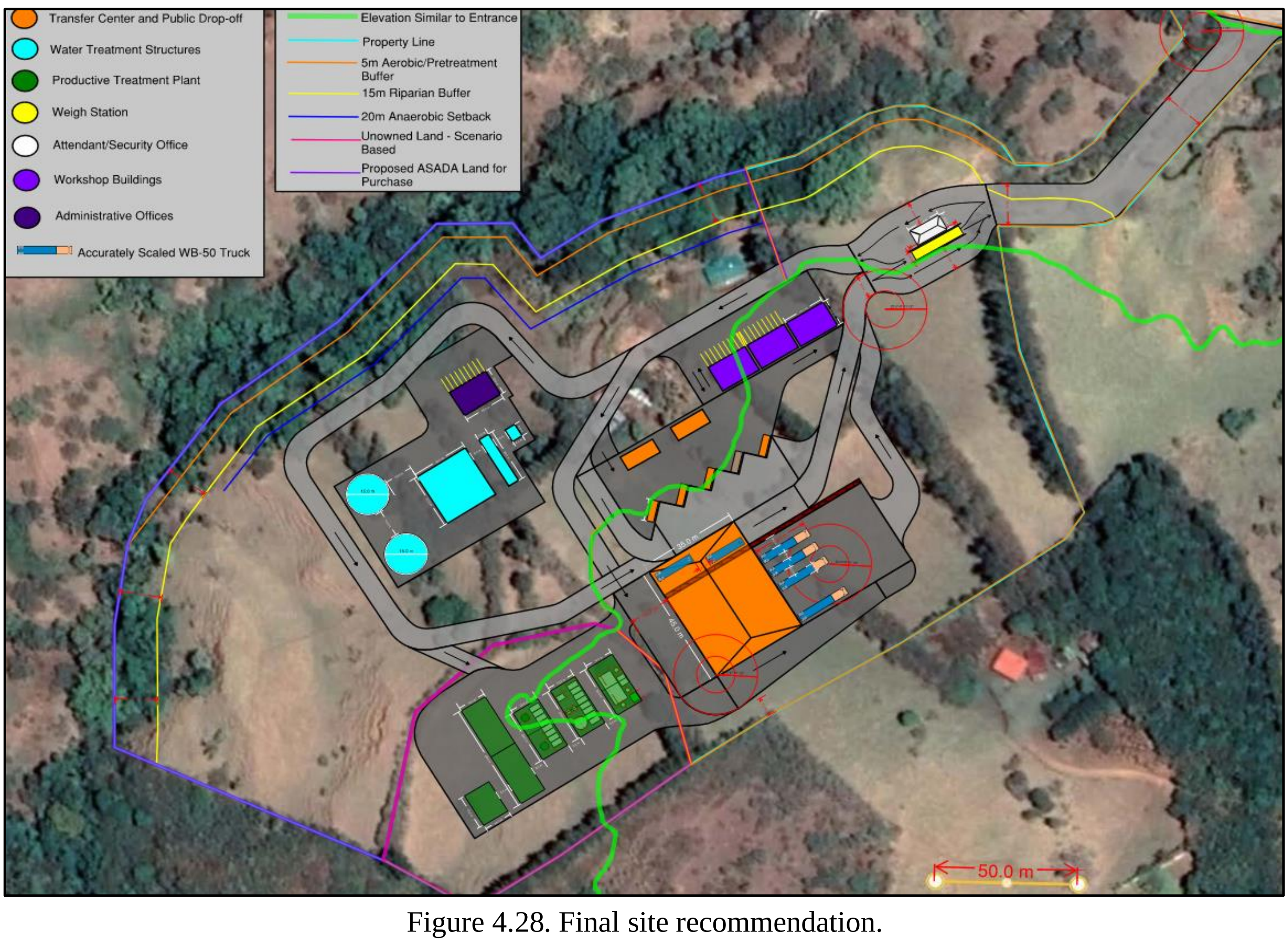


Figure 4.28. Final site recommendation.

This design includes an optimized placement of each site component with consideration for all legal setbacks, impact on surrounding land and neighbors, and utilization of existing site topography. In many of the components their multi-leveled construction meant they were oriented to match the slope and ideally minimize the earthwork necessary to condition the site. The roadway also connects all these components while allowing for vehicles to drive straight to one without driving through the others. While the team did their best job to design a site that tailored to all the limitations and constraints, it is not perfect. When considering the terraced site plan, there are many areas where the slope is beyond 35°, the maximum allowable slope before a retaining wall is built. The retaining wall at the transfer center alone is over 400 square meters of retaining wall blocks which means a large portion of any future construction budget would have to be allocated to these walls. Unfortunately, having to account for the large elevation difference within the buildable site area means these walls may be unavoidable. The extreme on-site topography also hindered the roadway design. When completing the transition to 3D, the team realized that maintaining a maximum 5% grade on the roads will be challenging. This is especially true when addressing the east side of the site where the large hill exceeds 20 meters in height. The road here may need to be curved back on itself to combat the intense slope, even though it may not be optimal for vehicles to navigate. Another potential design changing aspect would be a subsurface investigation. It is recommended that prior to the start of construction, a full subsurface investigation and geotechnical report be done on the site. This will assess the buildability of the site and ensure that the soil has the correct engineering properties for the building designs to prevent future disasters from occurring. Unfortunately, this assessment was not conducted while the team was completing the project, so the team lacked key engineering design criteria to support some decisions. When the ASADA determines they are ready to conduct such an examination, the data gathered will have to be used to cross-check the 2D and 3D site designs that the team created using assumptions. See Appendix D for the team's recommended preliminary subsurface investigation.

While it will not be an easy or straightforward path to completion, this project is achievable with enough diligence, time, and money. The team's design provides a conceptual understanding of the work it will take to finish the preliminary construction phase while giving the ASADA powerful visualization tools as they continue their efforts into the future. The team has done their best to head start the ASADA's project timeline as they gather more data about the site and ultimately move forward with the construction phases of the Monteverde Environmental Technology Park. The WPI MQP team wishes all the best to the ASADA as they work together with the Municipality and utilize their newly acquired funding plan. Hopefully the team will get to revisit the site in many years from now and see the hard work of everyone involved helping to keep the Monteverde community clean for everyone.

Appendix A: Proposal

1. Introduction

Monteverde is a municipal district located in the Puntarenas province of Costa Rica. Due to the presence of the Cloud Forest Reserve and many other beautiful natural attractions like the unique rainforest wildlife, tourists flock to Monteverde in mass. Tourism is so prevalent in fact that it comprises one of the largest economic sectors and makes Monteverde the 3rd most visited destination in Costa Rica (Brinkhoff, 2020). While bringing many economic benefits and new development to the area, the floating population of well over 150,000 people poses a host of issues for Monteverde's full time population of roughly 4,800 (Brinkhoff, 2020). In Figure 1.1 below, the main town of Santa Elena in Monteverde can be seen.

Figure 1.1. Main Town of Santa Elena

Monteverde is in the Cordillera de Tilarán mountain range and at the top of the region's watersheds causing it to have a direct influence on the surrounding environment and populations. Monteverde is currently facing a crisis of improper disposal and sanitation of sewage and solid waste.

This is where the ASADA, the local Environmental Management Program in Monteverde, plans to implement the "Monteverde Environmental Technology Park" in conjunction with the Municipal Council to address numerous aspects of this socio-economic waste problem. The three main components of the site will be the waste transfer center, productive treatment plant, and wastewater treatment facility. This development will be a common site for more political unity, promote synergy between waste management fields, and save money as the Monteverde community works towards the goal of being a zero-waste system (Welch, 2021).

The goal for the WPI project is to utilize prior project work, data from the chosen site location, and research by the ASADA and partners to design an overall site plan, earthwork design, and a 3D visual supplement for an Environmental Technology Park. The ASADA can then use this project as a tool to convey the functionality and short to mid-term benefit of the site as they work to receive more traction and funding within the Municipality.

2. Background

Costa Rica is a land of contrasts; banana plantations, flaming volcanoes, misty black sand beaches, and a thriving modern capitalist economy. A remarkably stable country, both politically and economically, Costa Rica offers an opportunity to become immersed in a Central American culture where democracy, economic development, and concern for the environment are a permanent part of the landscape. Monteverde was initially settled by American Quakers in the 1950s who purchased the land from local homesteaders and set up a small community of dairy farms. It has since become a major conservation and research hub due to its protected ecosystems and rich biodiversity (Desafio, 2021). The region currently hosts the largest network of private reserves of conservative land in Central America making the waste problem Monteverde is facing increasingly urgent.

2.1. Monteverde Waste Problem

In addition to the need for environmental and forest protection, Monteverde's current waste problem generates risks for public health, economic costs both at the individual level and at the community level, and contributes to climate change through increased greenhouse gas emissions (Welch, 2021). As a result of the increased demand for urban development there has been a consequential lapse in construction standards producing high levels of untreated greywater in the community. In addition, 98% of homes and businesses use septic systems as the main form of blackwater treatment and 66% of the septic sludge pumped is not adequately treated. This is due to an excessive strain on the waste management system where septic trucks have long inefficient routes and unregulated dumping is the unfortunate side effect. This matter is extremely pressing as rivers/streams in the distract have already shown contamination. If wastewater sanitation measures are not put into practice from both a prevention and treatment, there will be no clean water sources left for urban communities to come.

Figure 2.1. Monteverde Recycling Facility (Welch, 2021)

Solid waste is another aspect of Monteverde's waste management problem that needs to be addressed. In the current system, solids that go to landfills are losing significant efficiency in the compacting and transport routes of trucks that must drive many kilometers daily. The sorting of solids also poses an issue as the recycling centers are extremely limited on space (seen in Figure 2.1), and organic waste potential in terms of nutrients and energy is left unrealized.

However, the need for proper management of waste has not gone unnoticed by the Municipality and the ASADA del Distrito Monteverde. Their vision is one of a future free of contamination and full of opportunities to recover resources such as energy, nutrients, raw materials, and water for reuse. This future exists in a system that realizes a mutually beneficial relationship between urban and rural areas (Welch 2021).

2.2. Sponsor Background

Our project sponsor is Justin Welch who is the supervisor for the Environmental Management Program at ASADA del Distrito Monteverde, Costa Rica. It is an Association that provides, regulates, and guarantees the service of drinking water to communities in Monteverde (ASADA, 2021). ASADA knows that to enact a permanent and positive change, they must motivate the community to practice conservation and instill cultural values associated with the protection of clean water. To accomplish this, their mission is to apply an appropriate maintenance of the system, where the quality, quantity and continuity of the service is guaranteed at a fair cost. ASADA must be community leaders in the Monteverde District as the projection of their work protecting aquifers and treating wastewater will be critical in providing safe drinking water for the future generations to come.

Figure 2.2. ASADA washed and painted springs for "World Water Day" (ASADA, 2021)

The community of Santa Elena initially started with a supply of water from an artisan aqueduct that was in service for 30 years. In 1980, the first Aqueduct Administrator Committee was organized and only a few years later the water systems of Cerro Plano, Santa Elena, and Cañitas were united. Many years later in 1998 is when the ASADA known today was created to improve the water system. They started with the installation of a water disinfection system making it one of the first aqueducts with such high drinking quality. In 2008, due to the rise in tourism, expensive work began on the water system under the ASADA's supervision. In 2011, in conjunction with their governing body AyA, the project known by the community as kfw was created. By 2015 the project was complete, achieving a practically new Aqueduct, and with greater water supply capacity and sanitation standards. After completion this aqueduct was awarded 7 Stars in the Sanitary Quality Seal Program of the National Water Laboratory of the Costa Rican Institute of Aqueducts and Sewers (AyA), placing it as one of the best Aqueducts in our country (ASADA, 2021).

Today, the ASADA use their environmental and water conservation experience to forge the path towards a cleaner Monteverde. Their newest project, in collaboration with the Municipal authority, is a site development called the "Monteverde Environmental Technology Park" (PTAM) that integrates sanitation projects related to solid waste and wastewater. This multifaceted project plans to address many of the previously outlined environmental and public health crises that Monteverde currently faces and will grow alongside the developing community.

2.3. Environmental Technology Park

ASADA's mission in creating an Environmental Technology Park is to promote the ideal, productive, and innovative management of solid waste, liquids, and gasses for the Monteverde region. They seek to generate greater efficiencies in the development and provision of sanitation systems, maximize the transformation of waste into resources, and incubate new green ventures through Public-Private Alliances that link actors, infrastructure, services, and programs (Welch, 2021). This will act in such a way that Monteverde efficiently achieves local, national, and global goals in improving environmental health, human development, sectoral decarbonization, adaptation to climate change, and bioeconomy.

The PTAM was created considering a multitude of factors with related public policies at the national level and municipal strategic plans regarding wastewater, solid waste, and climate. In addition, the current low recovery rate of recoverable waste and the lack of community infrastructure for wastewater treatment made apparent the need to take advantage of new technological offers. The PTAM boasts ambitious goals but with a practical design it will allow the community to recover and transform a greater amount of solid waste, promote new mid-term ventures, and treat water for long-term reuse. Other considerable benefits of creating a larger single site are the shared/reduced development costs, joint management/operation, and minimized environmental impact. (Welch, 2021)

Figure 2.3. Transfer Center example (Welch, 2021)

The three main components of the Monteverde Environmental Technology Park are the transfer center, the productive treatment plant, and a wastewater treatment system. The main objectives of the transfer center are to promote consolidation strategies of recoverable and non-recoverable waste, facilitate efficient intermodal transfers and measurement, and provide new services and forms of waste management (ex. Construction debris, refrigerants, etc). It would modify the existing operations towards a third-party transfer and minimize local processing of cardboard, plastic, aluminum, and paper. This in turn would save 9 business days of work and create new collection routes in neighborhoods. (Welch, 2021) The transfer center will have the ability to be implemented in the short term and develop in stages which offers strong value for the Municipality. It will also allow for the inherent involvement of other initiatives with hopes to form long term alliances as the PTAM shapes the flow of waste in Monteverde.

The next component of the Environmental Technology Park is the productive treatment plant with the main objectives to integrate technologies that generate co-benefits for multiple sectors and to transform organic waste into energy, nutrients, and water. The current process of garnering resources from organic waste is using aerated static pile compost reactors. This uses a series of flow pipes that run into compost piles and provide oxygen to the inside which eliminates the need for manual turning of the piles and its associated labor costs. To supplement this aspect of the PTAM, there is also work being done to create an anaerobic co-digestion reactor with a batch stir tank. This reactor would take in a mixture of organic waste flows, of which the biggest concern being septic sludge and fat, oils, and grease (FOG). The reason this is such a waste concern for Monteverde is the increased urban development is producing larger amounts and these cannot be sent to a typical wastewater treatment facility. Luckily, the anaerobic co-digestion reactor will optimize composition, treatment services, and production of biogas by mixing the septic sludge and FOG with ground up food waste and dairy whey from the prevalent Monteverde dairy farms. Another positive output from the reactor would be the liquid digestate that can inoculate new compost batches and help treat pathogens coming out of the septic sludge through the solid's matrix.

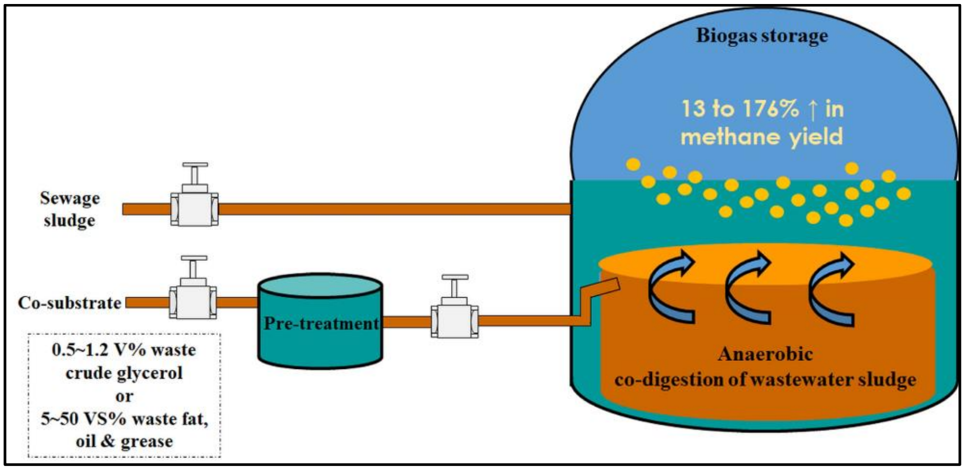


Figure 2.4. Anaerobic Co-Digestion Reactor Concept (Chow, 2020).

The final main component of the PTAM is going to be the wastewater treatment system. One objective for this system is to provide a sewage collection and treatment solution within the area for both gray water and black water. Ideally this will service the highest number of homes and businesses as possible and operate at low and efficient costs. Another objective for the wastewater treatment system is improving the water quality in Monteverde's most affected basins and preventing future contamination. This will work to ensure the public health and socio-economic well-being of local communities as Monteverde continues to be an increasingly popular tourist destination. A national university in Costa Rica is currently working on a comparison study of different configurations for the wastewater treatment train. This will produce a workable knowledge of space necessary on-site, flow into the facility, and operating efficiencies. In figure 2.5 below, the anticipated results of the PTAM can be seen for years to come.

Anticipated results:

Concept	Profits Goals	
Environmental	Greater recovery of recoverable solid waste	+ 358% by 2026
	Better wastewater sanitation 1,888 m^3 treated / day to 2030	
	Organic sludge transformed into resources for local use	By 2025, min. 239 m^3/ year transformed to biosolids
	Collection / storage of refrigerant gasses 50% by 2030	
	GHG emission reduction potential 1,667.23 tons CO_{2-e}/year	
Partner economic	Better low-cost sanitation services for: 6,500 local inhabitants 150,000	annual visitors 300 local businesses
	Organic inputs made available to local producers	At least 50 coffee, milk and vegetable farmers

Figure 2.5. Predicted benefits of the Environmental Technology Park (Welch, 2021)

2.4. Site Planning Process

General site design has 9 steps listed in Figure 2.6. When designing a site there are also environmental impacts that should be considered for conservation. It is important for wetlands, floodways, slopes, groundwater resources, woodlands, productive farmlands, significant wildlife habitats, scenic viewsheds from public roads, and historic, archeological, and cultural features (Lagro, 2011). These are important as they add to the overall appeal of the community, especially in a smaller one such as Monteverde.

Once a site is chosen, all relevant stakeholders have been engaged with, and the environmental factors are considered, the site design phase begins. In this phase some of the work conducted includes a feasibility study, schematic design, creating a site layout, preliminary building plans including elevation, schematic of circulation of buildings, and more. From there professional engineers can conduct a system study, and preliminary engineering layouts and engineering design as well as infrastructure construction documents. Then, landscape design is done, financial planning, impact analysis and finally construction management is done prior to the site being ready to begin preparation.

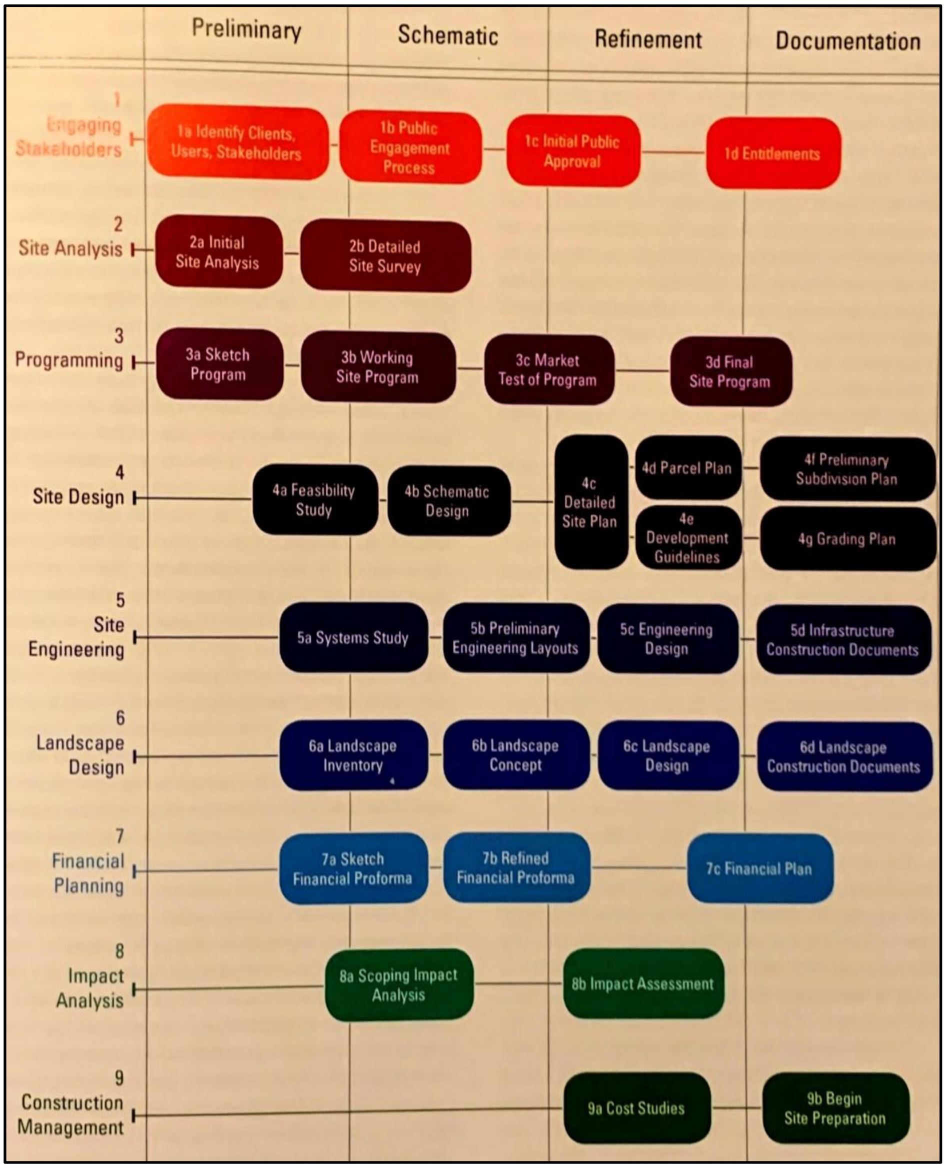


Figure 2.6. General site planning process (Hack, 2018)

2.5. Earthwork Design

Earthwork design is the process of using geotechnical data and soil reports to create a functional excavation plan for construction. This excavation plan brings the site from its existing topography to a proposed final grade that is suitable for the needs of buildings being developed. This is one of the earliest stages of the construction process and helps lay the foundation necessary to build. The process starts with subsurface investigations, such as borings or test pits, that help understand the quantities and structural properties of the workable soil present on site. This geotechnical data, combined with topographic data, can be used in computer software to create a model of earthwork necessary to achieve construction readiness. As seen in Figure 2.7, the proposed grades are modeled in a 3D space and show in relation to their elevation levels.

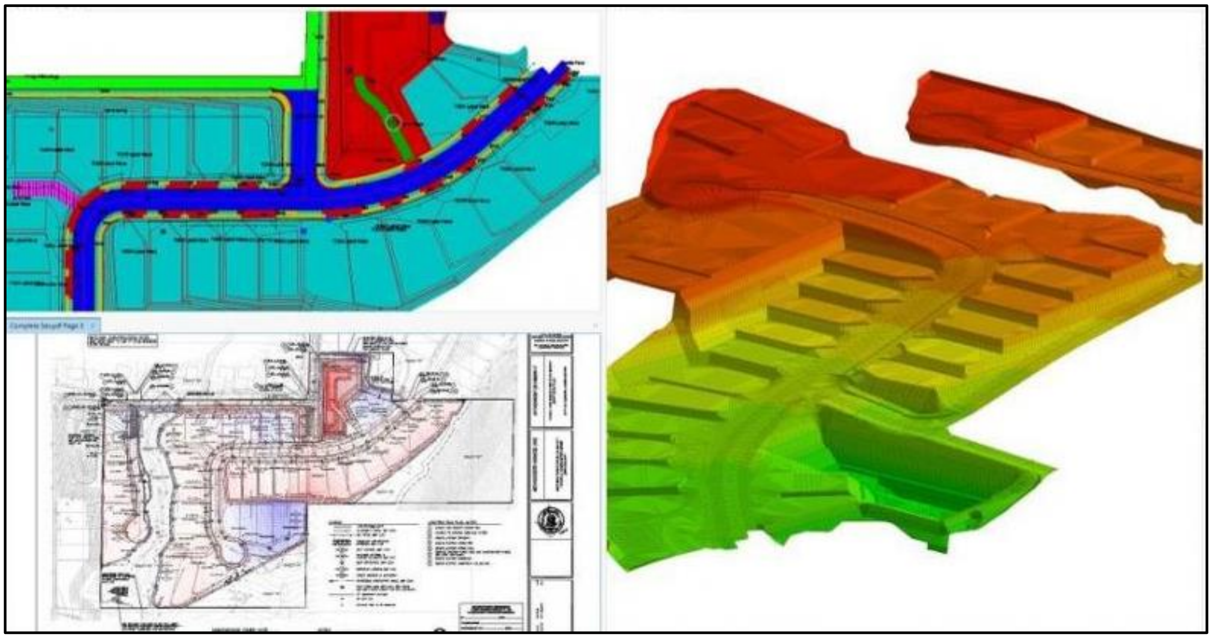


Figure 2.7. Earthwork Model displaying proposed grades (Clyde, 2021)

The reason it is so useful to create a model of the earthwork is because it can be used to calculate the exact cuts and fill for a project before excavation is underway. Ideally, a site can be created from the proposed grades where there is balance between cuts and fills and it is not necessary to import or export soil.

3. Methodology

The focus now shifts towards the process in which the ASADA plans to implement their Monteverde Environmental Technology Park (PTAM) as a solution to the underlying waste and wastewater crisis. Justin Welch and the Environmental Management Program have already found and purchased a site for the PTAM that is isolated from the surrounding community but in close enough proximity to service the Monteverde infrastructure. It also has the required features for a wastewater treatment facility (gravity fed system) and previous designation of pastureland. In partnership with the Municipal Council, they have acquired this large plot of land (about 8 acres) and now work towards receiving more funding and support to move forward with phases 1 and 2 of development. Phase 1 is the conditioning of the site to support all future development and phase 2 is the construction of the transfer station and productive treatment plant site components. This is where the WPI team can help provide value to the ASADA.

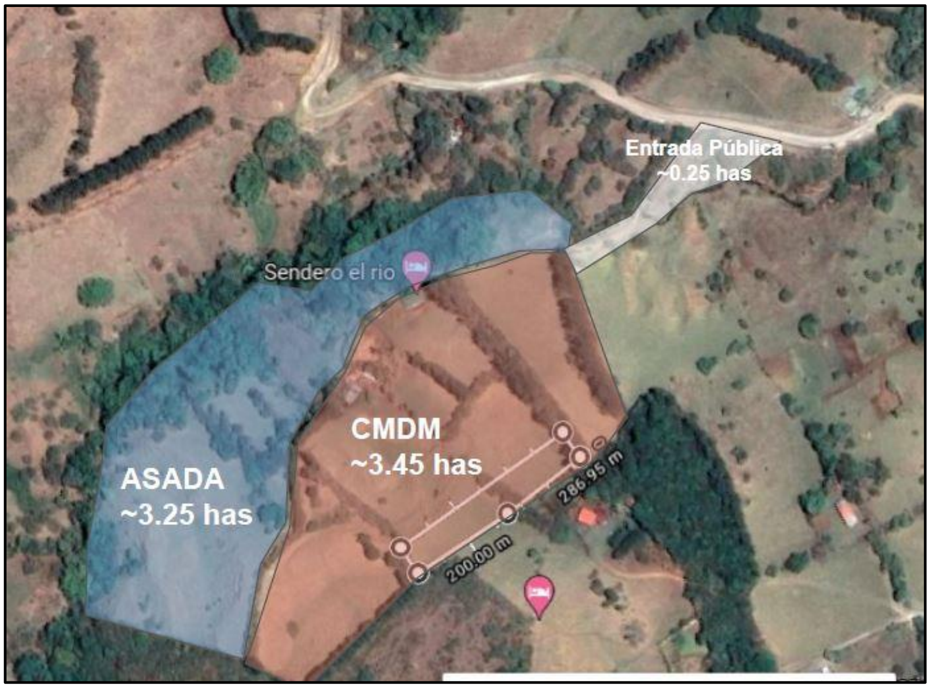
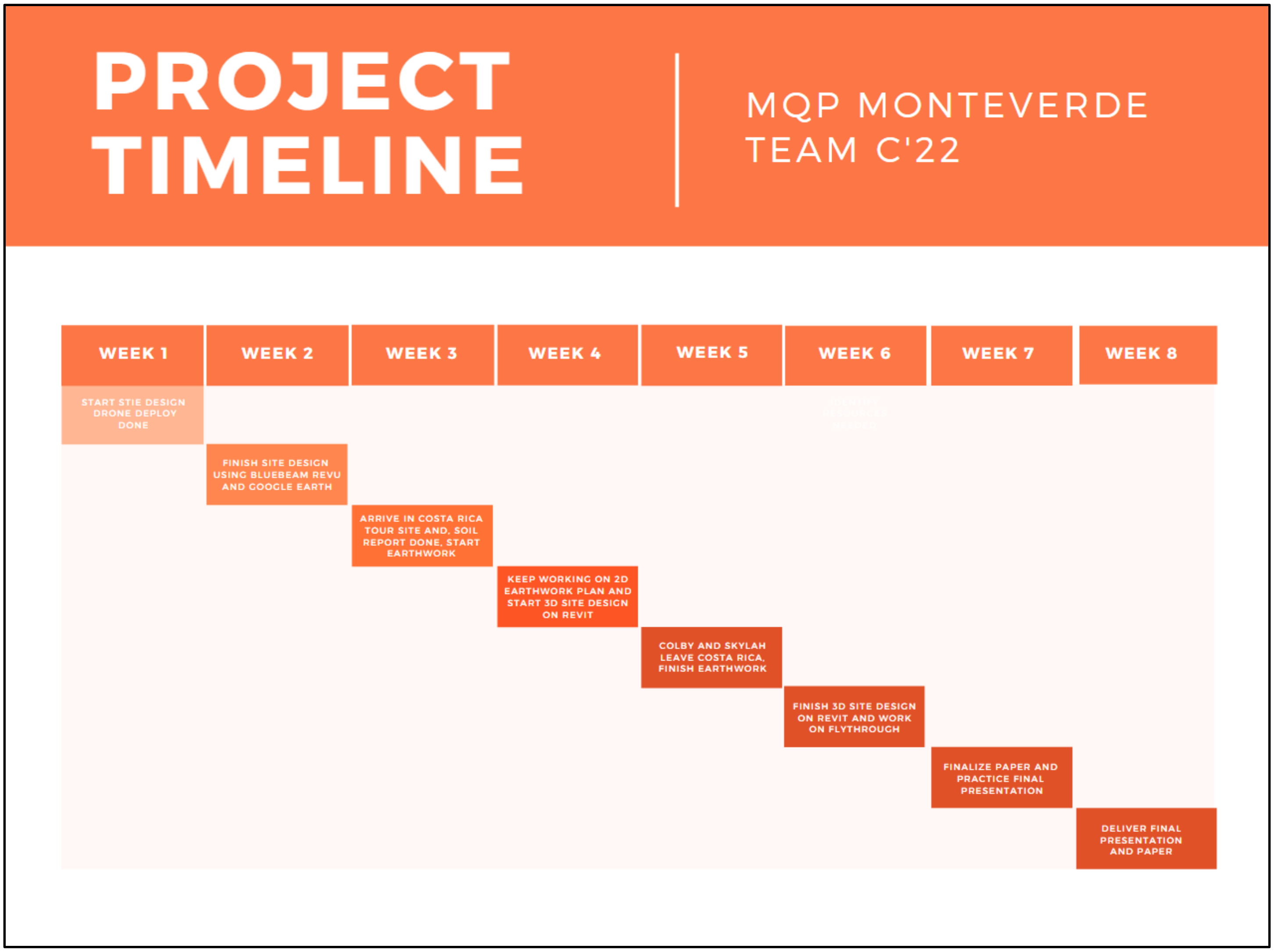


Figure 3.1. Purchased Site for the Environmental Technology Park (Welch, 2021)

The goal of our project is to aid our sponsor, the ASADA, in the preliminary construction process of the Monteverde Environmental Technology Park to complete the engineering requirements for our Major Qualifying Project, while also helping the ASADA garner stakeholder funding and community support for the PTAM. To accomplish our goal the team has laid out two main objectives:

1. Characterizing the project site.
2. Developing a 2D and 3D site design:
    a. Determine the required earthwork for the site including a proposed grading plan, cut and fill report, and earthwork model showcasing the transformation of existing topography.
    b. Develop true to scale 3D renderings for all the buildings and site components with a fly through of the site.



3.1. Characterizing the Project Site

To choose the most beneficial site the ASADA studied the feasibility of three sites and compared them. The first site examination was to locate geographic nodes with basic characteristics; slope, legal protection zones, and amount of forest cover were all considered. The availability of the different sites was then confirmed from the opportunity to buy the land to a Cadastral Study. A Cadastral Study looks at the exact property lines that could be used on a site. The third step taken was a direct comparison of site risks including determination of risk of landslides, land use verification or cooperation with existing zoning, and proximity to bodies that could potentially receive waste spill (Welch, 2021). Once the data needed was collected all sites were gauged against each other. In this step more project specific needs were weighed. In this project specifically the topography of the first site would be expected to keep infrastructure costs lower. Although in very close distance from the other proposed sites, this topography is desirable for the conceptual gravitational sewer system. After comparing their site assessments, the ASADA concluded that the first site option would be most desirable for the proposed project (Welch, 2021).

As part of our research and investigation of the ASADA's chosen site location, we have planned for a multitude of starting data sets for our project to be based upon. The first and most efficient method of data collection to be used is DroneDeploy. The company DroneDeploy offers many useful applications but for our project we are using their convenient construction solutions. They can create accurate, high-resolution digital replicas with 3D models, real-time 2D maps, and 360 fly-throughs for any construction site using advancements in drone technology. This will be conducted prior to our arrival in Costa Rica and be used as the starting point for an aerial view and 2D overview of the site while the digital 3D site model will serve as existing topographic data. The DroneDeploy data will then be transferred to BlueBeam Revu and used in the earthwork plan and cut and fill report. In figure 3.1 the functionality of DroneDeploy is showcased in a similar case to the Costa Rica site development.

Figure 3.2. DroneDeploy mapping capabilities (Ordiz, 2017)

Another form of data collection we plan on using is the subsurface investigation which should be conducted prior to or at the beginning of our arrival in Costa Rica. We have urged the ASADA to contract a preliminary study of the site's geotechnical properties and soil strata in the form of experimental borings and shallow test pits because they will need to be done eventually as this data is used in any construction project. Borings are much deeper in depth (typically 50-100 feet) and provide a sense of the strata down to depths. Test pits are much shallower exploring only to a depth of around 10-30 feet but provide much wider coverage of the site increasing confidence in the overall soil profile. Subsurface exploration is also used to collect soil samples from which simple laboratory tests confirm the moisture content, density, unconfined compressive strength, and location of the water table. This is all extremely relevant to our project as phases 1 and 2 involve site conditioning and initial PTAM development.

3.2. Site Design

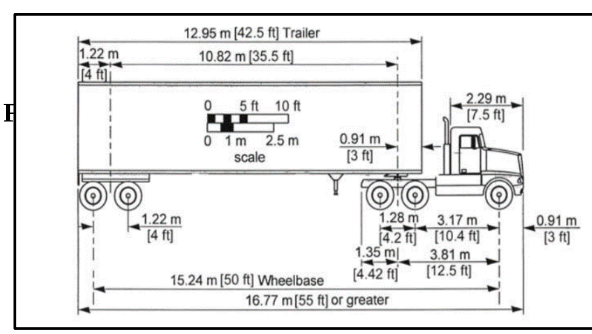
The site planning process seen in figure 2.6 shows all of the steps necessary for completion. However, at the stage of the project we joined, not every step needs to be taken. The first set of steps labeled "Engaging Stakeholders" falls more under the responsibility of our sponsor. The "Site Analysis" steps are crucial for our involvement in this project. Both initial site analysis and detailed site surveys are important for the rest of the site design. In this step we will arrange an assortment of site photos, maps, written descriptions from on-site visits, and any other notable features of the site.

The team plans to separate site design into two subsections, one focusing on 2D site design and the other on 3D site design. The 2D site design subsection will include conditioning the site with the proposed cuts and grades and an earthwork model showcasing the transformed topography, while the 3D site design subsection will include 3D renderings of the buildings and other site components and a visual flythrough of the site.

In Costa Rica, the Ministry of Health is responsible for permitting regarding construction of a wastewater treatment site. In Chapter II Articles 4 and 5 of the Regulation for the Approval of Wastewater Treatment Systems it is stated that they must approve a site before start of construction (Ministry of Health, 2016). To gain approval a letter must be sent including:

1. Global project name
2. Name of project lead
3. Location according to province, canton, and districts, with an attached copy of the registered map, updated without reduction
4. Exact site address
5. Brief explanation of what the treatment site will require
6. Brief explanation of the type, unit operations, unit processes, and equipment of the system
7. Proposed final facility for wastewater
8. Dumping permit granted by the Ministry of Environment and Energy (MINAE)
9. Overall plan of project in which system will be located including at least
    a. Proposed location of the area for treatment system, indicating preliminary dimensions
    b. Containing withdrawals to be kept between system and property boundaries
    c. If needed, proposed vent header or sewer connection location
    d. Acknowledgment on direction of water flow of any bodies of water on the property
    e. If applicable, location of existing wells and water supply within a 200 meter radius from plant

A large consideration for our site design is the accessibility of trucks needed both during construction and on-site when completed. Our site has a small land deformation that will need a bridge to allow safe access to vehicles. To design a small bridge, as well as an inner roadway system, truck weights, heights, and turning radii must be known. Information given by our sponsor suggests that the longest and heaviest truck will be the WB-50 (shown in Figure 3.3). The typical width not shown in Figure 3.3 is 8.5 feet. All dimensions considered, the minimum turning radius of this truck is 45 feet (NCHRP, 2003).



Various softwares will be helpful in the early stages of site design. Google Earth can provide a preliminary aerial view of the site (street view not available in our location) which can help to plan the layout of buildings. An image from Google Earth can then be brought into Bluebeam Revu. This software will allow the group to edit the same PDF document simultaneously so that we can easily manipulate different site options and draw on different road paths and layouts. Bluebeam Revu also features a tool that allows a scale to be set on an image. Setting a scale will then unlock an accurate measuring tool. This is a necessary tool for site design, especially in our case where all of us cannot be on site for the entire project. Google Earth is free to use while Bluebeam Revu offers a student license.

3.2.1 2D Site Design

To help understand the work necessary to condition the site for development, we plan to create an earthwork design in conjunction with our site plan. This will prove to be a helpful tool for the ASADA in the preliminary construction process as it will detail the steps necessary to transform the existing site topography into a workable plot of land. The site the ASADA has chosen to acquire is especially challenging in terms of existing conditions because it has a very high grade and will require significant terracing of the land. In figure 3.4, the steep terrain of the site can be visualized.

Figure 3.4. PTAM Site photo (Welch, 2021)

To properly condition this site with such large grade differentials, all the building plots will be built into the earthwork model to include stable soil foundations. When designing the terraces, it is important to understand there is a maximum allowable slope of the terrain before the design must be altered to include a retaining wall. For land that is not supporting an overlying structure, the maximum slope is 2:1 with a minimum slope of 2%. The slope may also need to be planted with ground cover to counteract the effects of erosion and must also be able to support maintenance equipment such as lawn mowers (GSA 2019). Another element of the proposed grading will be the connecting road network. The biggest factor when grading roads into an earthwork design is consideration of the slope. While Costa Rica fortunately does not get snow that will freeze over roadways, the maximum allowable slope of a road will still be designed as 5% to accommodate for the large waste transport trucks that will be utilizing the on-site road network.

To accomplish this task, we will use the Autodesk software "Civil 3D" with the grading optimization add on. This makes use of the data produced by the DroneDeploy program which will appear in Civil 3D as a topographical model. This topographical model has assigned elevation values that will interface with a proposed grading design the team develops. Figure 3.5 to the side showcases the DroneDeploy import and its resulting existing grade model with associated workable values. This is important because the software will process the steps necessary to achieve our designed grades and output quantities of earth relevant to its construction. It also works within the constraints of what is physically possible and will be flexible to our inputs/grading parameters. As operators of this software, we have complete control of the earthwork model through manual changes we make to the proposed grading plan as well as specific inputs we make into Civil 3D. The result will be a workable 3D model of the new and ideally balanced site (equal cut and fill) with a report of exact earth quantities to excavate.

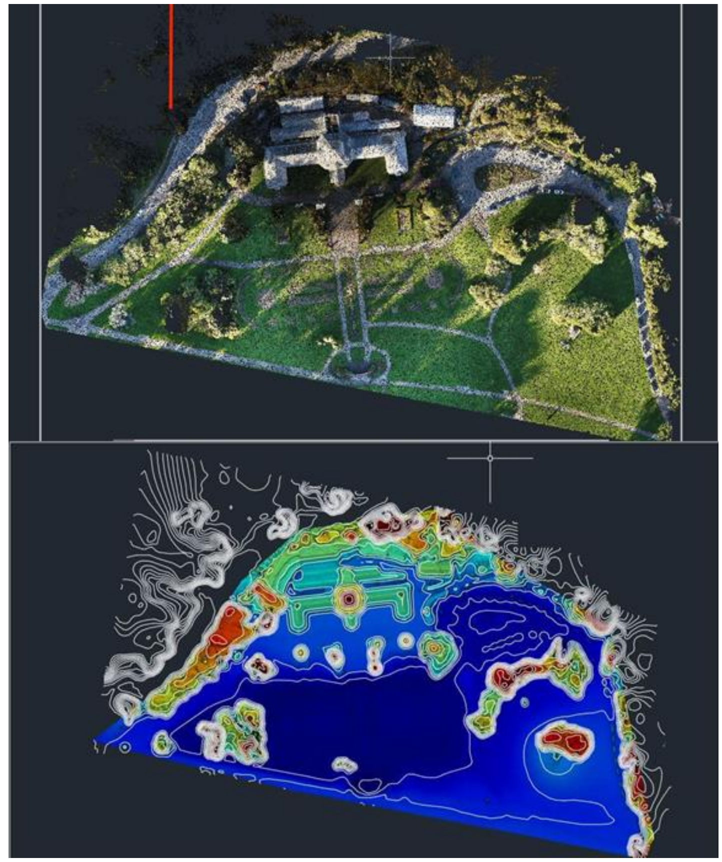


Figure 3.5. DroneDeploy existing grade model

Below an example of our resulting earthwork model can be seen in Figure 3.6 of the Civil 3D grading optimization software. This work can then be imported into the other Autodesk software we will be using called "Revit" and provide a foundation for our 3D architectural renderings.

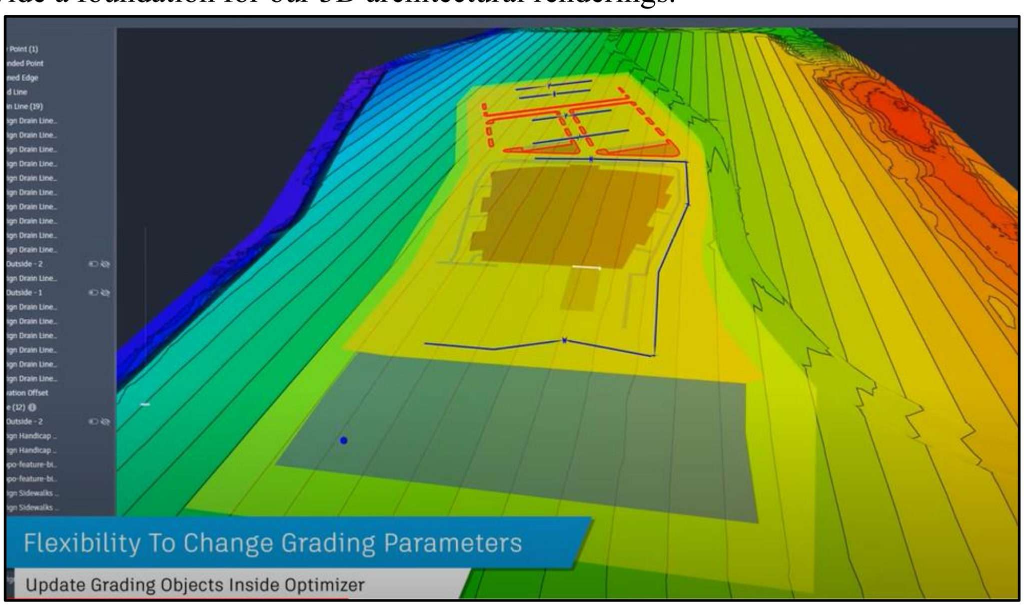


Figure 3.6. Implementing parameters in Civil 3D Grading Optimization (Sayre, 2021)

3.2.2 3D Site Design

Autodesk Revit is a building information modeling (BIM) software for architects, landscape architects, structural engineers, mechanical, electrical, plumbing engineers, designers, and contractors. It can be used for planning, designing, constructing, and managing buildings and infrastructure. Revit allows users to create, edit, and review 3D models in exceptional detail. Revit allows for the creation of 3D renders, 3D perspectives, detailed drawings and walkthroughs. Using measurements from the project site, true-to-scale drawings of the buildings can be constructed in Revit. These drawings can include interior and exterior designs as well as landscaping, people, and other site components. With these drawings the team will create a 3D rendering of the buildings in the proposed Monteverde Environmental Technology Park, as well as a visual flythrough of the site which will be used to garner stakeholder support and funding and showcase the site to a variety of audiences. .

Figure 3.7. Revit 3D exterior rendering example (Autodesk, 2020)

3.3. Project Utilization

This project will benefit ASADA and their goal of creating an Environmental Technology Park because they are in the early stages of development and require further funding for capability growth and land acquisition. Our project aims to give the Municipal government in Costa Rica a better understanding of ASADA's vision for PTAM through detailed site designs and layout, an earthwork model, and architectural renderings.

Appendix B: Terms of Reference from ASADA

1. **Roofline:**
    a. Min. 4 m roofline at eaves
    b. Arched
    c. High wind load capacity
2. **Building width:**

. Sufficiently wide enough so that the far end (low side) can accommodate 2 transfer trailers (approx. 30m total)

3. **Building length:**

. 20 m to accommodate 5 loading bays plus free space for truck maneuvering

4. **High side:**

. Oriented toward the upper slope on the South
a. Low-slope ramp to allow large trucks to back into building
b. Open floor space (no columns) to allow for free truck/equipment movement

5. **Low side:**

. 2 truck lanes to drive under respective tipping floors
a. Min. 4m clearance below tipping floor to allow transfer trailer drive under
b. Curved angles to allow for truck alignment (entrance and exit)

6. **Recyclables Drop-off side:**

. 3 Loading bays with heights for Municipal collection truck (dbl axle), smaller collectors (single axle cargo) and average pickups/cars

7. **Recyclables Storage/Takeaway side:**

. 5 Loading bays for 19m WB-50 trailers (1 per category of material + 1 free space)

8. **Lots space:**

. See needed specs for maneuvering space requirements of respective vehicles

***We should discuss alternative scenarios to the tipping floor design of non-recoverables based on potential limiting factors.**

Terms of Reference for Transfer Center Main Building

1. **1st level Drop-offs**
    a. Septic sludge (large trucks- w/o trailers gravity discharge to lower tanks) 1x 5,000 cylinder tank (1.7m diam x 2.55 m height)
    b. FOG (buckets and barrels) 1x 1,950 cylinder tank (1.7m diam x 2.55 m height)
    c. MSOW (buckets and barrels)
    d. "Brown waste" (wood chips, leaf litter and reused course material) (10m x 20m)
    e. Chicken manure (550 sacks) (5 m x 12 m)
    f. Treated wastewater storage tanks 2x 5,000 ACD mixing tank (1.7m diam x 2.55 m height)
2. **2nd level Mixing area**

. Main compost mixing floor (10 m x 15m
a. 8x ASC chambers (4m depth x 2m width x 1.5 m height each)
b. MSOW hammer mill and feed system to mixing tank (2m x 3m)
c. 2x 5,000 ACD mixing tank (1.7m diam x 2.55 m height)
d. Biogas storage unit (5 m diameter)

3. **3rd level Turning and finishing area**

. 4 ASC chambers (4m depth x 2m width x 1.5 m height each) + 4 open areas w/o aeration (4m length x 2m width)
a. 2x 22,000 L ACD reactors (3.0 m diam x 3.56 m height)

4. **4th level Drying, sifting and storage/loading**

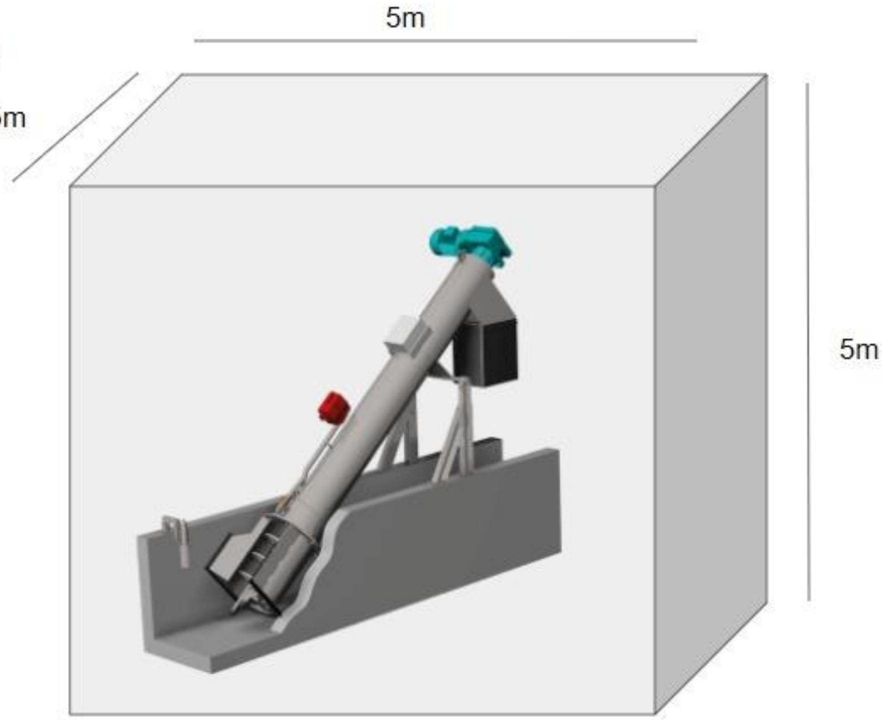
. Drying floor (10m x 20m)
a. Conveyor/sifting technology
b. Zone for finished material storage/aging/packing/truck loading (10m x 20m)

5. **Accessory systems and spaces**

. Water, electrical, aeration and drainage lines
a. Electrical room, pump and motor (3 m x 4 m)
b. Tool storage and repair shop (2.5 m x 3 m)
c. Wastewater treatment and recirculation system (125 m2)

Terms of Reference for Productive Treatment Plant

WWTP: PRE-TREATMENT
Large Particle Removal w/ Endless Screw

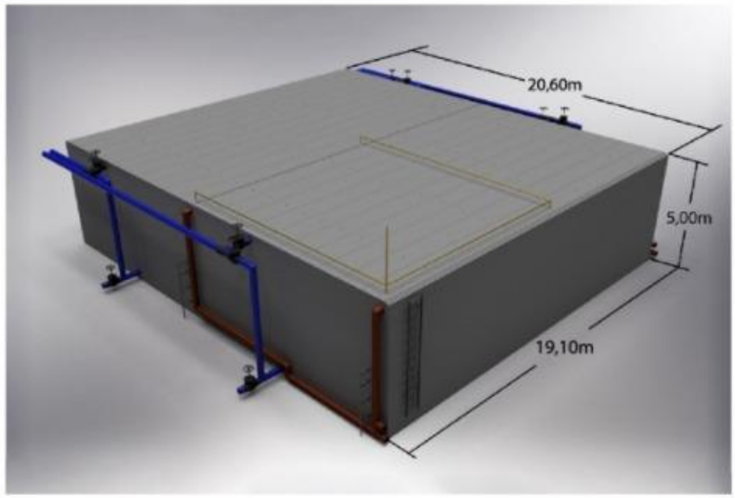


WWTP: PRIMARY TREATMENT
Fine Grit Sedimentation

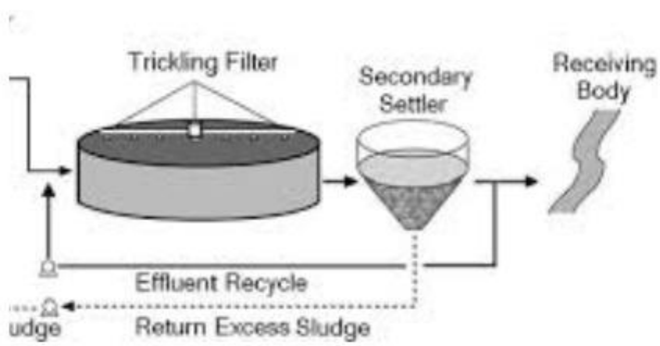
Only an example and estimated dimensions based on comparison to human references in image

WWTP: SECONDARY TREATMENT
Anaerobic AFAF

capa fija. La Figura 17 muestra una vista general del diseño propuesto y el anexo 5 detalla las dimensiones de cada cámara en una vista de planta.



WWTP: SECONDARY TREATMENT
Trickling Filter (r = 10) & Secondary Settler (r= 5), both with a heigth of 2.5 m (estimate)



WWTP: SLUDGE TREATMENT
Sludge Drying Beds (x5)
Length = 4 m
Width = 2 m
Depth = 1.5 m

Estimated based on site visits

Terms of reference for Wastewater Treatment Plant

Appendix C: Interior Renderings

Transfer Center Office

Transfer Center Breakroom

Administrative Office Reception Area

Double Office in the Administrative Office

Appendix D: Recommended Preliminary Subsurface Investigation

Site reconnaissance is the first stage of site investigation. In this stage, visual inspection of the site is done and information about topographical and geological features of the site is collected. The general observations made in site reconnaissance are as follows :

1. Presence of springs, swamps, wetlands, etc.
2. Presence of vegetation and nature of the soil.
3. Past records of landslides, floods, shrinkage cracks, etc. of that region.
4. Study of aerial photographs of the site, geological maps, etc.
5. Observation of deep cuts to know about the stratification of soils.

Subsurface exploration data is the next step, where the soil sample is collected from experimental borings and shallow test pits, and simple laboratory tests such as moisture content test, density, unconfined compressive strength test, etc. are conducted.

Simple field tests such as penetration methods, sounding methods, geophysical methods are performed to get the relative density of soils, strength properties, etc. The data collected about subsoil should be sufficient enough to design and build light structures. Following are some of the general information obtained through primary site exploration.

1. Approximates values of soil's compressive strength.
2. Position of the groundwater table.
3. Depth and extent of soil strata.
4. Soil composition.
5. Depth of hard stratum from ground level.
6. Engineering properties of soil (disturbed sample)

General Subsurface Testing Guidelines (Potential Contracting):

- Borings:
    - 4 needed (1 per 2 Acres)
    - 400 ft minimum separation
    - 30 ft minimum depth
- Test pits
    - 16 scattered test pits across site
    - 10 ft minimum depth

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