Life Cycle Assessment of Titanoboa and its Activities

Report Prepared at the Request of EatART, in Partial Fullfillment of UBC Geog 419: Research in Environmental Geography, for Dr. David Brownstein

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Introduction

This project is focused on conducting a life cycle assessment (LCA) on Titanoboa, which is a 35 foot long electromechanical snake (EatART). In its current state the snake weighs 1 ton and is 35 feet long, but it is currently being enlarged and in its final state it will be 50 feet long (EatART). It is remote controlled and is capable of 5 different modes of motion. Its body is made of aluminum vertebrae with internal lighting and animated eyes (EatART). This assessment will follow Titanoboa from its design and construction to its use and eventual disposal. This study will provide an evaluation of the total energy consumption of Titanoboa along with its carbon footprint and recommendations for carbon footprint reduction. In order to conduct this study I used the LCA software called Quantis.

This evaluation is conducted for the benefit of EatART, an educational non-profit organization founded by artists, designers, and engineers, who voluntarily construct large scale kinetic and robotic sculptures. These sculptures are used as public educational tools, aimed at increasing awareness and to raise questions about current energy consumption patterns. A major part of the educational public involvement includes regular long distance travel for these projects, which are regularly displayed at exhibitions, fairs and venues across North America. This extensive schedule is the reason why EatART is concerned and interested in learning about the carbon footprint of their activities. This LCA will be extremely beneficial for the organization because it is not site specific and with their extensive travels it will assist EatART in learning about the carbon footprint and energy consumption patterns of Titanoboa as it travels to various venues.

Ultimately this paper aims to answer the question put forward by EatART: What is the total energy and carbon footprint of Titanoboa, and its environmental education activities. After an analysis of its creation and its activities I aim to provide EatART with recommendations and suggestions that do not compromise on the quality or scale of their educational outreach programming.

Life Cycle Assessment

According to the International Organization for Standardization (ISO) life cycle assessment is defined as the “Compilation and evaluation of the inputs, outputs and potential impacts of a product system throughout its life cycle” (International Organization for Standardization). While conducting a life cycle assessment you are following a product from its cradle to its grave. ISO standards outline a set of fixed protocol for performing a LCA study which is referred to as the methodological framework of an LCA (Baumann and Tillman 2004). ISO divides an LCA study into four different phases: goal and scope definition, inventory analysis, impact assessment and interpretation (Baumann and Tillman 2004). Following the ISO methodology, I have divided the rest of the paper in these four phases, explaining my observations and analysis along each step.

Goal and Scope

Titanoboa is a reincarnation of an ancient 50 ft long serpent which became extinct due to climate change (EatART). This project was created for educational purposes: “to provoke discussion about our daily energy use and climate change in a historical context” (EatART). EatART’s mandate is to educate people about energy use and climate change through the creation of large pieces of art but they have not conducted a complete study on how their actions and initiatives are impacting climate change. EatART asked for this study to be carried out for the purpose of identifying which activities in the life cycle of Titanoboa contribute the most to the environmental impact associated with this product and what are the improvement possibilities in the life cycle of Titanoboa. Titanoboa does a lot of traveling so EatART identified that as their biggest concern and asked me to focus this study on transportation. The goal of the study includes providing EatART with recommendations on how to efficiently transport artwork to various destinations while minimizing their carbon footprint. Hence the intended audience of this study is the organization, because they want to use this study as a benchmark for other projects, which would eventually result in reorganizing their transportation methods.

Due to time constraints and the well defined focus requested by EatART, I was unable to follow Titanoboa from its inception i.e. raw materials acquisition. I have only focused on three life cycle stages for Titanoboa: design and construction, usage and deconstruction. The design and construction phase includes all the materials, lab and energy consumption by various tools. The usage phase includes Titanoboa's travels over the past year, the different modes it has used for traveling and the generator or solar energy used to charge Titanoboa. It was hard to create a system boundary around these three life cycle stages because of the fact that Titanoboa is a moving object, which requires people to constantly travel with it across North America. But I set the EatART lab as the boundary this includes the materials and tools in it used to construct Titanoboa.

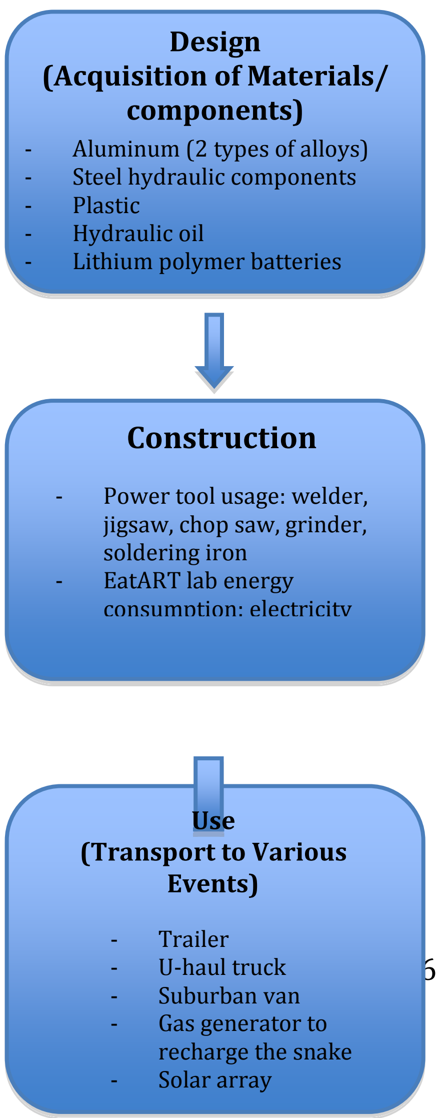
I had difficulties choosing a functional unit which would describe product processes in a comparative framework focused on environmental impacts versus educational outreach. It is very hard to express the function of Titanoboa in quantifiable terms, as a functional unit because it is a moving piece of art. Its main function can be described as an educational or entertainment tool used to increase environmental awareness. In order to quantify its main function I would need data about the number of people “educated” or impacted by this artwork. Acquiring this data was extremely difficult, time consuming and inaccurate. Since EatART’s focus is on the transportation phase of the lifecycle, I quantified impacts per event because the delivery of the artwork became the focus. Thus the functional unit is defined as impacts/kilometers (KM) traveled, multiplied by the weight of the truck with the passengers, weight of the trailer carrying the artwork, weight of the artwork being carried, weight of the people traveling with the artwork. Usually EatART transports their projects on the road via a trailer pulled by a truck or pulled by their house car called the suburban (Brinson 2012). The trailer is sometimes shared by 2 projects so the weight of the other project becomes an important factor distributing potential environmental impacts (Brinson 2012).

Transportation is EatART’s major concern, which is why I focused my investigation on Titanoboa’s impacts on climate change. This is one of the limitations of this study because I did not look into other impact categories such as impacts on resources or biodiversity. Another limitation to this study is the fact that in its current state Titanoboa is only 2/3 completed which is why the project lead Charlie Brinson provided me with rough estimations of the data I needed. I had to rely on him as a primary resource for data collection because he is the only one who knows how much aluminum, steel and other materials were acquired to construct the snake. He is also the only person keeping a log of Titanoboa’s travels and the actual distances covered. I do not believe my data collection method will be a problem because this is not a comparative study because there has been no previous study like this, hence it is actually a benchmark study for future EatART project comparisons.

Life Cycle Inventory Analysis

The inventory analysis (LCI) is the second phase of the LCA study and is directed by the goals and scope discussed in the first phase (Guinee et al. 2002). The life cycle inventory analysis phase includes a flowchart documenting all modeled activities and the flows between them (Baumann and Tillman 2004). Figure 1 shows the flow chart for Titanoboa highlighting the relevant activities.

FIGURE 1: Flow Chart



Project lead Charlie Brinson provided me with all the numbers I needed regarding the materials and energy consumption and transportation. To validate the data I also compared some of his data with other sources, for example he told me that each of the thirty-two lithium batteries used in Titanoboa were 24 volt each, I compared this number against an online data source (Brinson 2012). Appendix A provides all the data that was collected from Charlie and it also shows how the data was standardized and converted into different units for the LCA software Quantis. There are multiple programs that perform LCA's using internationally recognized databases (LCA Alliance). I was advised to use Quantis for this paper by the LCA Alliance at UBC because it has the largest volume of data about emission factors focusing on transportation (LCA Alliance). Quantis is a software that people use to assess and manage their environmental impacts uses technology and various internationally known databases (Quantis 2009).

As you can see in Appendix A under the use phase there are various modes of travel. EatART either attaches their trailer to a rental U-Haul truck or they use their lab car which is a 1996 Chevrolet Suburban (Brinson, 2012). They are also thinking of investing in a new passenger van either the Chevrolet Express 3500, GMC Savanna 3500 or a Ford E-350 (Charlie). I wanted to compare the modes of transport in order to identify the most environmentally friendly. In order to conduct a comparative analysis I first had to standardize the data. In my functional unit I decided to quantify impacts/ per event and focused on weight. I added up the weight of the artwork and the weight of the U-Haul truck and the trailer or the weight of the suburban and the trailer and multiplied that by the total kilometers traveled by Titanoboa. The end result gave me a unit of metric ton-

Kilometer for each of the modes of travel. I also did the same for the Chevrolet Express, GMC Savanna and the Ford E-350 in order to provide EatART with the best solution.

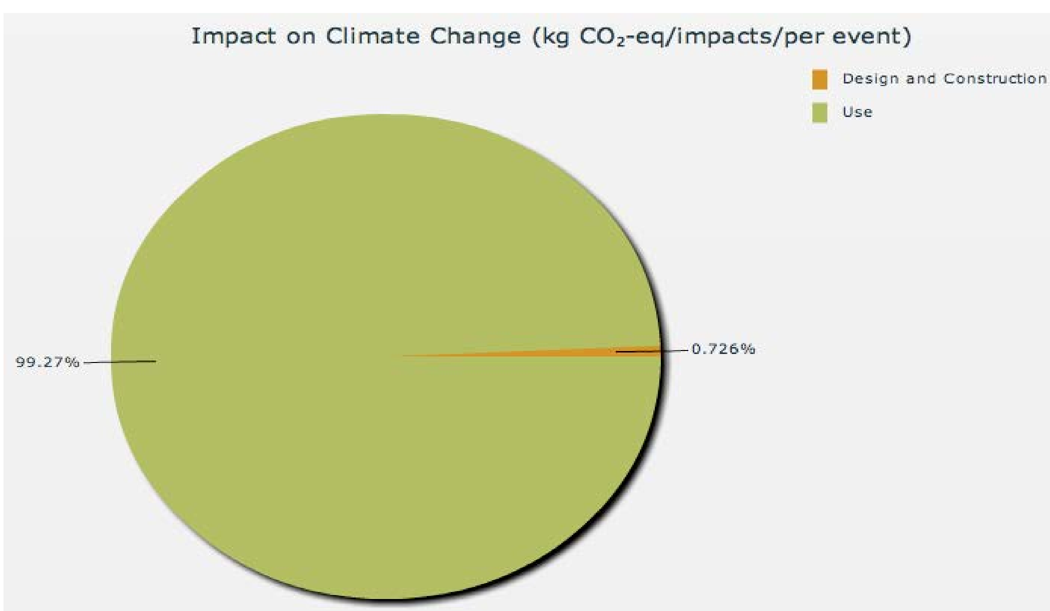
Quantis allowed me to set up the structure of the study according to the goals and scope defined earlier. In Quantis data was classified under the following headings: design and construction, use and end phase. I did not enter any data for the end phase because I was told that eventually Titanoboa will be displayed permanently in a museum. After adding the numerical data in Quantis for each of the phases, I used data sets to add input and output flows. Flows are seen as inputs into the system to create Titanoboa so flows are the raw materials acquired by EatART (Quantis 2009). Flows in Quantis are attached to flow types that generally describe what the flow represents and the units of measurement (Quantis). A good example of this is the amount of electricity consumed by the EatART lab while constructing Titanoboa, thus the flow type in this situation is electricity. Each flow I entered in Quantis I added corresponding environmental factors which are processes describing the production methodology (Quantis). The databases that Quantis uses helps because they have pre-calculated emission factors attached to each process associated with a flow.

Impact Assessment

The third stage of a LCA is the Life cycle impact assessment (LCIA) which describes the environmental costs of the environmental loads identified and quantified in the previous phase (Baumann and Tillman 2004). There are various LCIA methods which aim to connect each life cycle inventory result with corresponding environmental impacts. Quantis uses IMPACT2002+ as a LCIA methodology (Quantis 2009). IMPACT2002+ links all the inventory results to 14 midpoint categories including ozone layer depletion, global warming and human toxicity, to four main damage categories: human health, ecosystem quality, climate change and resources (Jolliet et al). This study focuses on transportation, which is why I chose climate change as the only impact category of interest, in order to understand the effects of Titanoboa's travel activities. In Quantis and IMPACT2002+, climate change represents the impact on global warming and is measured as the total emissions of CO2, and its associated unit is kg CO_2- eq (Jolliet et al).

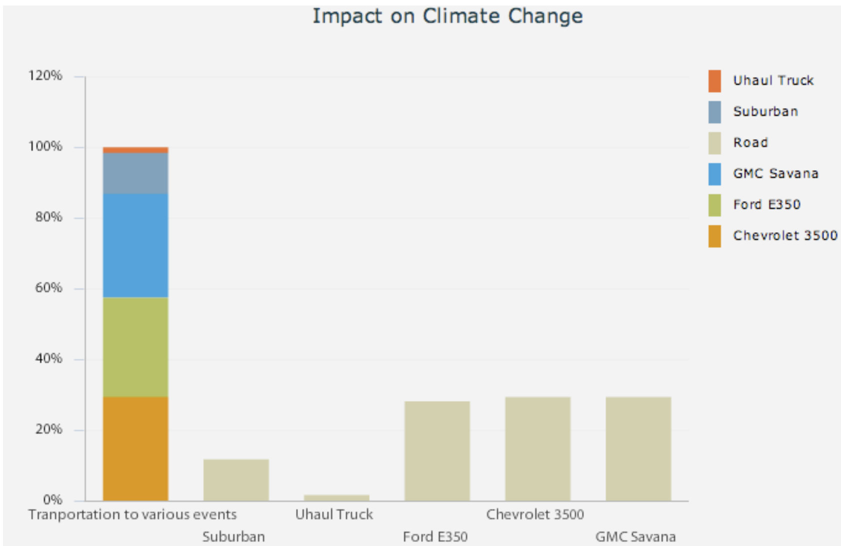
According to the analysis Titanoboa's design and construction phase resulted in total emissions of 3,322.17 kg CO_2- eq, while the use phase produced 454,339.29 kg CO_2- eq (Quantis 2009). These results were expected, and they justify EatArt's decision to focus this study only on the transportation impacts. Figure 2 provides a representation of the comparison between the two phases.

FIGURE 2: Comparison between the Design, Construction Phase and Use Phase



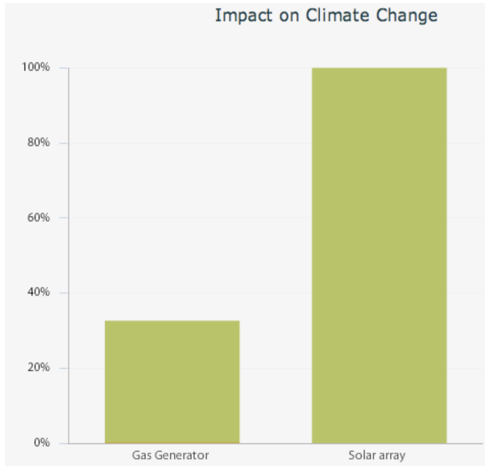
Analyzing the various modes of travel was extremely important because this is one way EatART can reduce its carbon footprint. Figure 3 shows a view of the impact of climate change caused by the various modes of travel.

FIGURE 3: Comparison between Modes of Transportation



EatART usually also carries their solar array or a small gas generator with them to charge Titanoboa at various events. I compared their efficiency's in terms of transportation to see which one would have a lower impact on climate change. Figure 4 shows the results of this comparison.

FIGURE 4: Comparison between Transportation of Solar Array and Generator Set



Interpretation and Recommendations

The last phase of a LCA is the interpretation phase, for the purposes of this paper I have grouped this phase along with the recommendations. After interpreting the analysis there are 3 important recommendations I will forward to EatART.

1- It is clear according to Figure 3 that their current car the Chevrolet Suburban is causing the maximum impact on climate change if you compare the suburban with the U haul. Renting a U-Haul truck might cost them a little more, but in terms of environmental damage the U-Haul is causing is 7'066.41 kg $CO_{2\text{-eq}}$ emissions, while the Suburban is causing 52'485.5 kg CO_2-eq. But these numbers appear to be less significant when I look at the numbers associated with the other vehicles EatART is thinking of purchasing. The GMC Savanna and Ford E-350 would emit 132'218.17 kg of CO_2-eq. This is significantly more than the U-Haul truck and the Suburban. My recommendation to EatART would be to look for better alternate vehicle options. It seems that the size of the van or the truck they would like to invest in is an important determining factor. The U-Haul truck has better fuel efficiency over longer distances, which is why it has lower carbon emissions compared to the Suburban. EatART was also thinking of investing in a diesel engine in order to use biodiesel as a fuel. A study done by Nocker et al concluded that fossil diesel fuel is environmentally better than biodiesel taking into consideration all the assumptions made by the authors for the LCA (1998). Even though biodiesel performed better for the global warming potential indicator it did perform much worse for other impacts such as acidification, water, eutrophication etc (Nocker et al 1998). The total social costs which include private production costs and external environmental damage cost are higher for biodiesel than for fossil diesel (Nocker et al 1998).

2- The figures above not only show the variation associated with the different modes of transportation but also that there is a significant amount of environmental impact being caused by the transportation of these heavy objects. These numbers in some ways contradict EatART's mandate of spreading awareness about current levels of energy consumption. I cannot recommend artists to not create huge pieces of art and I also cannot recommend them travel shorter distances. But what I would recommend that they conduct a life cycle sustainability analysis on their activities. This could be as easy as a cost and benefit analysis. My suggestion would be for the artists at EatART to sit together and make a radius around their lab which is where the artwork is stored. This radius should reflect the locations they can travel to before the costs of their traveling become higher than the benefits. In order to figure out the benefits they could consider the number of children they have educated over the years or at specific events they have participated and impacted people's energy consumption patterns. They can compare this data against the environmental impacts caused by transportation. This will not only help them focus on local venues but also to hopefully realize that in some situations the distances they travel to increase energy awareness overshadows the costs they are paying in terms of the impact on climate change.

3- After comparing the effects of carrying a solar array and a gas generator I would recommend to EatART that they carry the gas generator when they are covering longer distances. The longest distance they have traveled has been to NYC which is 4800 km away from the EatART lab, while the shortest distance they have traveled is 8 km to the Vancouver Art Gallery. In my analysis I also factored the amount of fuel used for the gas generator and its effects on climate change but these are overshadowed by the weight of the solar array. Solar arrays are extremely heavy; each set weighs 200 pounds and provides 600 Watts of energy. Titanoboa needs 1200 Watts of energy to charge at an event. This means EatART has to carry two sets of solar arrays on each trip but occasionally they also need to carry the generator as a backup depending on the time of year and amount of sunlight available at their location. They do not always get peak energy output from the solar panels each day. This is why I would recommend that they carry the gas generator, which weighs 70 pounds, over longer distances because it will be more efficient and it will cause less environmental damage than the solar array. Also they will not be dependent on local weather conditions.

Study Limitations

There are various limitations to this study a few of them I have already mentioned above. Titanoboa in its current state is not a complete finished product because EatART is still building upon it so most of the measures given are rough estimates of what the finished product would have consumed.

Another important limitation to consider is the allocation of the energy usage in the lab. Since the EatArt lab is shared by different teams working on different projects all the estimates of energy used from the lab on Titanoboa are rough estimates.

Another limitation to this study would be the fact that I have only focused on climate change which gives me a very narrow perspective on the environmental impacts being caused by EatART's activities but I did this in order to fulfill the desires of the organization.

Future Research

As I suggested earlier a life cycle sustainability analysis would be extremely beneficial for this non-profit educational organization. LCA has previously focused on environmental impacts but life cycle sustainability analysis has the capability of including various other dimensions and relationships which would allow EatART to compare and examine their environmental impact versus their mandate of public outreach. Currently my study only focused on the artwork and the modes of transportation but I believe it is important to also look at the number of people they come in contact with over the multiple exhibitions and fairs they present at. This analysis will help them consider the offset of education on the carbon footprint of the project itself.

APPENDIX A:

Design	**Data as collected**	**Standardized Data** (For the purposes of the software)	**Assumptions**
Aluminum H116 alloy 70% H32 alloy 30%	5100 cubic inches	83. 57 kg H116 = 58.499 H32 = 25.071	
Hydraulic oil	7.5 US gallons	28.4 kg	
Hydraulic components	41 hydraulic cylinders each one 5 lbs of steel = 205 lbs total	92.99 kg	
HDPE polycarbonate plastic	13000 cubic inches	213 kg	
32 Lithium polymer batteries	Each battery is 0.754 kg	24.128 kg	Since each battery is 0.754 kg so multiplied that by 32.
Construction			
Welder	6 k W for 400 minutes	40 k W h	Converted 400 minutes to hours = 6.667 6 k W multiplied by 6.677.
Jig saw	780 Watts used for 1000 Minutes	13 k W h	Converted 1000 minutes into hours= 16.67 780 W converted to k W = 0.78 k W. multiplied 16.67 h by 0.78 k W.
Chop saw	1200 Watts for 30 minutes	0.6 k W h	Converted 1200 W into k W = 1.2 k W

			Multiply 1.2 k W by 0.5 hours.
Grinder	500 Watts for 2000 minutes	0.6 k W h	Converted 500 W into k W= 0.5 2000 minutes into hours= 33.33 hours Multiplied 0.05 k W by 33.33 hours.
Soldering iron	50 Watts for 15000 minutes	12.5 k W h	Converted 50 W into k W = 0.05 kW 15000 minutes into hours = 250 hours Multiplied 0.05 k W by 250 hours.
EatART Lab	- 8 x 80 W fluorescent lights - 8 large sodium lights 1 k W each.	- 197 k W h - 2457.6 k W h	- Lab is shared between other projects so in order to allocate Titanoboa's share I added up all the minutes the power tools were used to construct it to get a rough estimate which was 18, 430 minutes = 307.2 hours. 80W x 80 = 640

			W. Converted 640 W into k W = 0.64 k W. 0.64 k W multiplied by 307.2 hours = 197 k W h. - 1 k W multiplied by 8 large lights = 8 k W. 8 k W multiplied by 307.2 hours = 2457.6 k W h
Use			
U-Haul Truck + Trailer	U-Haul truck weight: 12,000 pounds Trailer: 1920 pounds	27'303 metric- tons Kilometers	I needed to convert the data given to me into metric- ton Kilometer to be able to input this data into Quantis. I added the weight of the trailer and the weight of the snake and multiplied that by the total distance Titanoboa has traveled so far which is 15270.1 Kilo meter. I did not add the weight of the truck itself because Quantis lets you pick the type of the truck as an environmental flow which has

			pre-calculated data on the weight of the truck, its fuel efficiency etc
Suburban + Trailer	Suburban weight: 5551 pounds	27’303 metric- tons kilometers	I followed the same procedure outlined above.
Ford E-350	Ford weight= 5584 pounds	65’830 metric- tons kilometers	I added up the weight of the trailer and the snake and multiplied that by the total distance traveled. Again I did not add the weight of the car itself because Quantis uses its databases to do that.
Chevrolet Express 3500	Chevrolet weight= 6009 pounds	68’780 metric- tons kilometers	Same procedure as above
GMC Savanna	GMC Savanna weight= 6009 pounds	68’780 metric-tons kilometers	Same procedure as above.

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