UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

U-Square Mobile Phase Two

Lauren Anderson, Zhuheng Cai, Jocelyn Chung, Wen-ding Tseng, Nicholas Yap

University of British Columbia

MECH 457

Themes: Community, Climate, Energy

April 22, 2019

PHASE TWO

MOBILE²

FINAL REPORT

Team Members
Lauren Anderson
Zhuheng Cai
Jocelyn Chung
Wen-ding Tseng
Nicholas Yap

Sponsor: AMS/ SEEDS Sustainability
Faculty Supervisor: Dr. Jon Mikkelsen
Liaison: Sam Tuck
Date Submitted: 22 April 2019
Word Count: 2,091

Executive Summary

U-Square Mobile is a sustainability project proposed by AMS Sustainability and SEEDS. It's meant to highlight the possibilities and limitations of wind energy as an alternative source of energy in light of the increasing effects of climate change. As a prominent structure in a high traffic area on campus, it serves as both an artistic structure while providing a starting point for conversation about sustainability amongst the public. This is Phase 2 of the project, and this year, the focus was to design and develop the artistic and interactive element of the structure. The design objectives for this project were to design and build an aesthetically pleasing structure, capture wind energy, educate the user about alternative energy, and maintain its functionality in all weather.

The project deliverables designed by the team were the headpiece and user interaction subsystems. The headpiece consists of an off-the-shelf vertical axis wind turbine and rotating artistic beams mounted to the top of the structure. Through mathematical models, the material and sizing of the headpiece was completed to design the system with sufficient safety factors. The user interaction system consists of a display board, a hand crank. The display board contains a message about wind energy, power generation information, and local weather information. The power generation portion compares the power generated by the wind turbine and the user with power consumption of typical household electronics. The user interacts with the structure by turning the hand crank to generate power, and through gesture controls in front of the display board to display weather information such as temperature and humidity. Analyses and tests were done to determine the optimal dimensions for the hand crank and system functionality of the user interaction interface.

Due to funding constraints, the project could not reach the level of completion originally intended. The delays that arose from this hampered the design and construction phase, leaving several components at the virtual model stage. This influenced the difficulty in designing the electrical system where more robust testing and testing for full functionality were unfeasible. Upon reflection, knowing the state of funding earlier and a more definitive deliverable would have made the project run more smoothly with less compromises. If this project were to be done again, the team would ensure that the client had a concrete and prioritized list of deliverables and evaluate that list as a team to determine the feasibility of completion.

The recommendations to the client are in regards to the project's next steps: the structure design should be finalized with confirmed pricing, the selected wind turbine should be purchased, the headpiece should be fabricated at a welding shop, a date for structure installation should be decided, and a Phase 3 should be proposed to electrical engineering capstone groups. There is significant work remaining for the electrical system which the team believes would be better handled by an electrical engineering capstone group. These recommendations assume that the available funding is enough to cover all costs. If this is not the case, and the funding is insufficient, we recommend not proceeding with the project further.

Table of Contents

List of Figures

1.0 Objectives

U-Square Mobile is an artistic structure put forth by AMS Sustainability and UBC SEEDS Sustainability Program to showcase alternative energy in an interactive piece for the community. It will be placed in the U-Square plaza between the AMS Student Nest and Robert H. Lee Alumni Centre. As the effects of climate change are becoming more apparent every year, greater awareness is needed. This structure aims to showcase the potentials and limitations of one such renewable energy source, wind power. Phase 1 of this project last year focused on the feasibility of designing a vertical axis wind turbine that would generate power to charge mobile devices. Phase 2 of the project this year continues this investigation while also focusing on completing the design of the structure with artistic and interactive elements to attract the public.

The main objectives for this project were to design and build an aesthetically pleasing structure, capture wind energy, educate the user about alternative energy, and maintain its functionality in all weather[1]. Due to the low wind speed conditions at the planned site, the plan to charge mobile devices at the structure was modified. The energy generated is now used to power the structure's interactive elements.

2.0 Design and Testing

2.1 Design Overview

The structure consists of a main 12-ft steel structure, designed by Michael Kingsmill, which the wind turbine and artistic element sits on top of. The user interaction element is housed on the main body of the structure, at a height about 3-ft. The main subsystems designed by the team are further described below[2].

[1] See Dossiers 1, 2, and 5 for project specifications and evaluation criteria

[2] See Dossiers 8, 10, and 11 for technical analysis and detailed designs of components

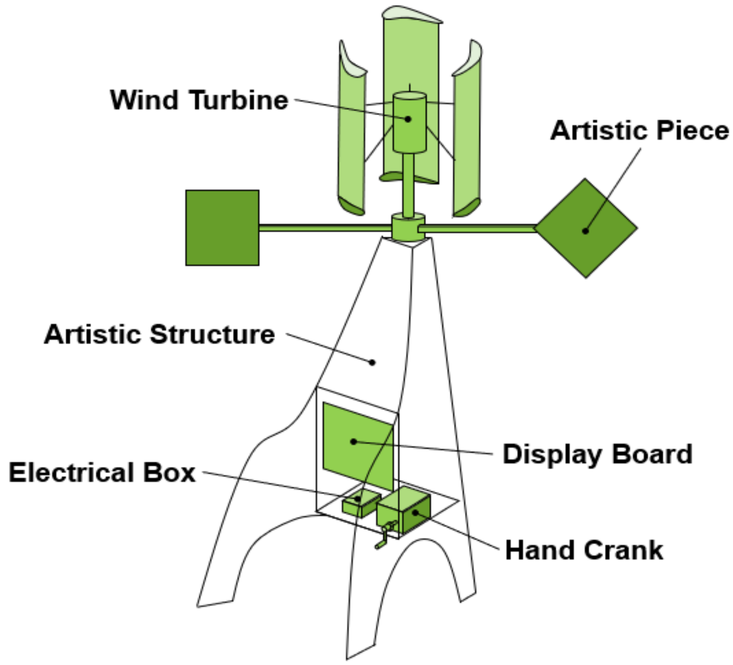

Figure 1: Finalized design layout of U-Square Urban Turbine

2.1.1 Headpiece

The headpiece consists of a vertical axis wind turbine (VAWT) and a rotating artistic element. The artistic element is two aluminum rectangular beams with geometrically shaped fins attached at the ends. The fins act like a weather vane so the beams can rotate when there is wind. The artistic element and wind turbine are connected to a central aluminum shaft that is welded to a base plate and connected to the top of the structure.

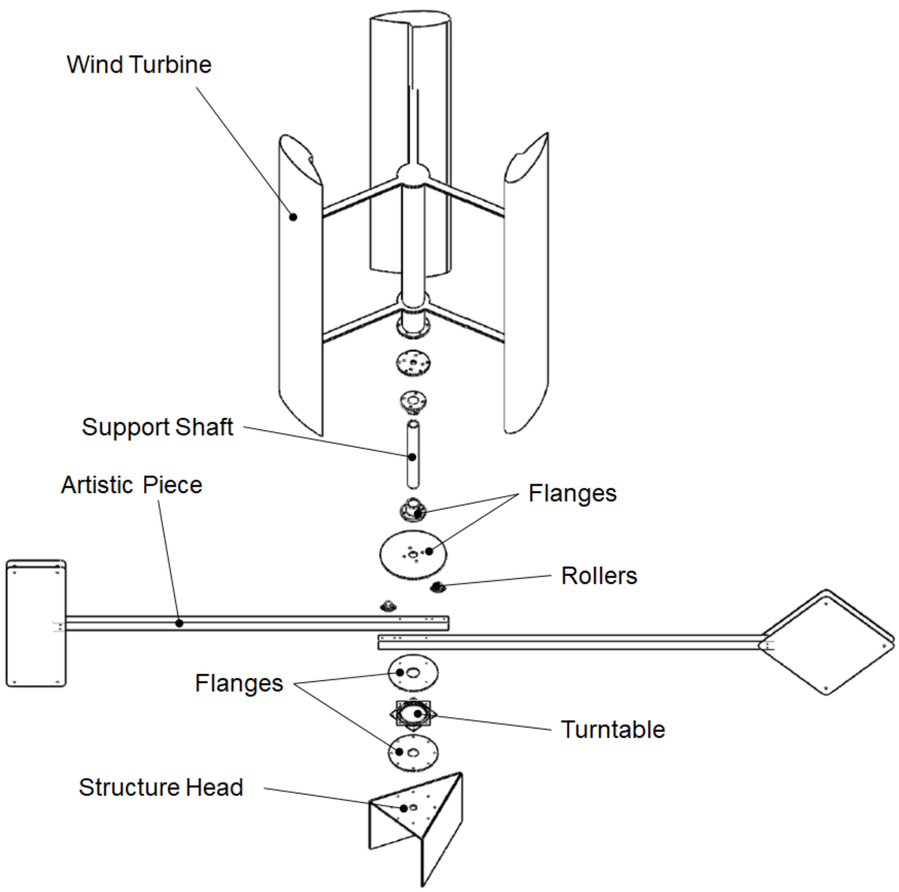

Figure 2: Annotated exploded view of the headpiece

Phase 1 worked towards building a custom wind turbine. This had limited success because the expected wind speeds did not generate enough force to surpass the starting torque needed for the generator. With this knowledge, Phase 2 decided to purchase an off-the-shelf VAWT and incorporate the separate artistic piece which spins freely around the VAWT support shaft.

2.1.2 User Interaction

The user interaction consists of a display board and a hand crank system. The interface is designed to allow the user to approach it, read about the structure, and discover how the system operates. The goal of this system is to educate the user on wind power and provoke thought about power generation and consumption in daily life.

The display board is the main face of the user interaction element, where information about the project and its objectives are explained for the user. It also consists of 7-segment LED displays that create a weather station with information about temperature and humidity around the structure. There is also a scale of the power consumption of common household electronics. This scale compares the wind turbine power output to its possible household uses by lighting up LEDs in increasing increments. Finally, the display houses two LED displays which compare the real time power outputs of the wind turbine and the hand crank. The power comparison and the LED power scale are activated when the user turns the hand crank. The weather station and power readings can also be activated using gesture control.

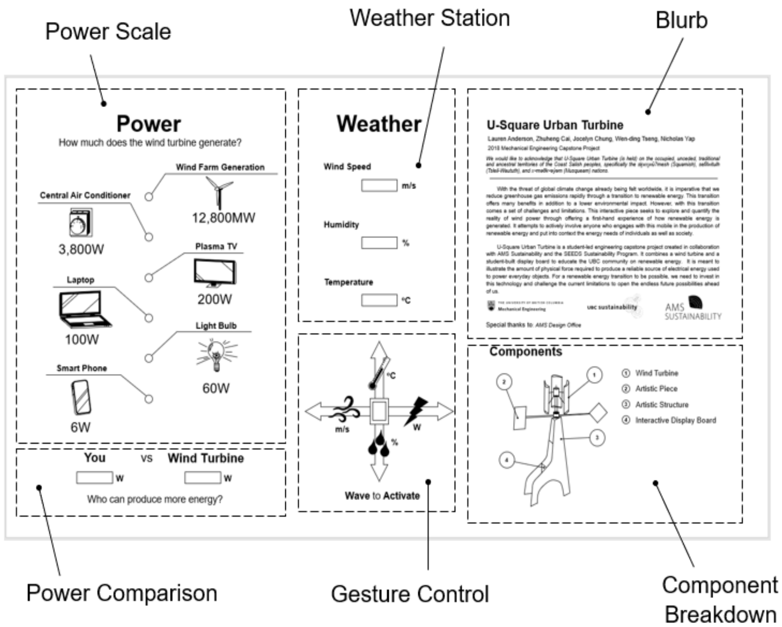

Figure 3: Annotated Display Board

The hand crank system consists of a hand crank that can be turned by the user to power a generator and produce power. It gives the user an idea of the effort required to generate power. The crank is connected to a gear train and a generator. This generator is designed for use in a wind turbine. It includes an emergency brake which is activated at 450 RPM which equates to a cranking speed of approximately 200 RPM.

2.2 Detailed Design

The final product includes each subsystem to different levels of completion. All mechanical systems include full engineering drawings for the client so that they could be produced as needed in the project construction timeline[3]. The headpiece has not been built and thus no physical tests have been performed. It was tested only through mathematical models. The user interface has been constructed for testing purposes and hand-off to the client.

[3] See Dossier 11 for engineering drawings

2.2.1 Headpiece

2.2.1.1 **Procedure**

The headpiece was modelled in several ways. Initial prototyping involved numerical optimization of the geometry and material of the artistic beam[4]. Following this, bearing load calculations were done and the bearing system was prototyped to scale with the proposed turntable and ball transfer components and a wooden frame[5]. With the success of the artistic piece rotational system and a design for the beams, detailed design was pursued. The entire headpiece was modelled in SolidWorks and revised through design reviews with the team and instructor. The central shaft was checked mathematically to ensure the dimensions and material could support the expected loads[6]. The critical welds and bolted connections were also checked to guarantee the safety of the design[7].

2.2.1.2 Results

The results of these tests are as follows. The entire headpiece is constructed of aluminum with stainless steel fasteners. This guarantees the longevity of the product in outdoor conditions while maximizing the strength and minimizing weight. The artistic piece beams are made of 1.5” x 2” x 0.125” rectangular tubing which has a safety factor of 1.92 for the estimated loading scenario. The cross-sectional area was minimized whilst keeping strength in mind, leading to the most discreet beam design possible. The central shaft is a size 1.5 aluminum pipe. The safety factor is 1.17 under a maximum estimated loading scenario. The weld and bolt connections have safety factor ranging from 5-10. These values indicate that the design is strong enough without being overbuilt. The headpiece has been completed to the engineering drawing stage.

2.2.2 User Interface

2.2.2.1 Hand Crank Characteristics

The hand crank was designed with several critical characteristics in mind. These were:

- Crank handle length
- Mounting height[8]
- Gear ratio[9]
- Power output

The final handle length was constrained by off-the-shelf market availability. The mounting height was set to 36 in based on ergonomics research. A power curve was created for the

[4] See Dossiers 7, 8 for critical functional prototype analysis on beam bending and CES material selection
[5] See Dossier 10 for headpiece prototyping details
[6] See Dossier 8 for central shaft analysis
[7] See Dossier 11 for detailed design related to headpiece safety calculations
[8] See Dossier 8 for crank height optimization
[9] See Dossier 8 for gear train analysis

generator. An estimate for average human cranking speed was made and compared to the generator speeds required to output the required power. In an iterative process, gear ratios were chosen to step up the input speed. The required force on the crank was then determined and compared to ergonomic research on human cranking force capabilities. From this process a gear ratio of 2.2 was chosen with an ideal maximum power output of 60 W. The gear stress analysis has a safety factor of 16 under the expected loads.

2.2.2.2 Electronics

The electrical system was designed and built based on the needs on the interconnected subsystems[10]. It evolved over many months based on the inputs from the team, client, and instructor. Limited testing was done on the final system, but what was completed led to tuning of system parameters to improve the user experience. Testing was completed for the following:

- The ability to accept user inputs through the gesture control.
- The ability to measure local weather statistics.
- The ability to accept and measure the hand crank power output.
- The ability to direct the desired data to the correct display or LED.

Problems occurred when directing the data to the correct displays. The 7-segment displays are differentiated using addresses unique to each display. An error occurs which causes the displays to reset to the stock address, which is the same for all of them. Additional problems are caused by the battery. The current battery is not suited for high cycle charging and discharging and no longer functions properly.

2.2.2.3 System Performance

The entire system was tested to ensure the physical prototype functioned as expected. The results showed how the system fulfilled expectations and where it could be improved. The output power from the hand crank was tested to generate a power versus speed curve[11]. The electrical displays were coded to display the data as detailed on the assembled display board. When the functional system was presented to the user it had the ability to convey its message and accept user inputs[12]. The final prototype needs electrical improvements as outlined in section 2.2.2.2 above and proper, long-term wiring connections. It also requires weatherproofing of the final display board assembly.

---

[10] See Dossier 10C for the interactive system prototyping information
[11] See Dossier 12 for verification testing
[12] See Dossier 12 for validation testing

3.0 Conclusions

The state of the final prototypes and designs did not reach the level of completeness originally intended by the team. Funding complications prevented the majority of the prototyping from happening until late February and thus many components could only be completed to the engineering drawing stage. The other main hurdle was tackling the immense task of designing and programming the electrical system. This task should have involved more robust testing and troubleshooting with the final products, but late assembly of other subsystems prevented these tests from occurring. Additionally, the wind turbine could not be purchased and therefore no testing or incorporation of the wind turbine was possible.

From the issues surrounding this project we can reflect on how this project could have run more smoothly. If we had started the project knowing the reality of the funding we could have planned to deliver something more realistic, and possibly more complete. The initial expected deliverable of an entirely completed and installed structure was likely too large of a task. By the end of January the deliverables had become a set of subsystems that could be installed later. This changed every aspect of the project and most subsystems were redesigned. If we were to do a project like this again the first thing to do would be to ensure that the client has a concrete and prioritized list of deliverables and then to evaluate those deliverables as a team to determine the feasibility of completion.

4.0 Recommendations

The recommendations are as follows, listed chronologically:

- Finalize the structure design and confirm the pricing.
- Purchase the wind turbine from our contact at Aeolos.
- Fabricate the headpiece at a welding shop using the provided engineering drawings.
- Set a firm date for the structure installation
- Propose a Phase 3 to the electrical engineering capstone groups.

The remaining work needed to complete the user interface is significant. The existing electrical system is preliminary and needs work to be a reliable part of the final structure display. Additionally, once the wind turbine is available it will need to be incorporated into the electrical system. We believe that the best way to complete these tasks would be to enlist another capstone group. This group would have the advantage of knowing exactly what the required inputs and outputs of the electrical system would be. This firm set of deliverables would help ensure that a final product could be obtained. The tasks required by the next team would be:

- Incorporate power inputs from the wind turbine.
- Source an appropriate battery for energy storage.
- Complete the weatherproofed display board with proper wiring connections.
- Replace the prototype breadboard with reliable connectors (PCB, prebuilt connector units, or other).
- Test prototype to confirm functionality.

If another capstone team is not pursued, the above tasks would need to be completed by existing team members working on a volunteer basis, or by hiring a third-party. These recommendations assume that the funding available is enough to cover all costs. If this is not the case, and the funding is not available, we recommend not proceeding with the project further.