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CHRISTCHURCH NEW ZEALAND

18/05/16

Fletcher Vaughan

Fletcher Systems

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Dear Mr Vaughan

Mid-Year Report: Kinetic Pillar Sculpture

The Kinetic Pillar Sculpture team is submitting the attached Mid-Year Report to provide an update on the details of the project. The main focus of the report is to outline the research, concepts and prototypes already completed, as well as to inform you about the next stages of the project. We aim to begin the testing on the scaled sculpture in August, with ample time to 'fine-tune' the design.

This report includes information on the designs and builds so far, additional research, updated costings and a timeline for the remainder of the project.

We are satisfied with the project progress thus far and look forward to continuing with the project.

Regards,

Sam Godsiff,
Rachel Henderson,
George Legget,
Christopher Matthews,
Bobby Richards

Department of Mechanical Engineering

ENME408 Final Year Projects

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MID YEAR REPORT

KINETIC PILLAR SCULPTURE

21 May 2016

Prepared by
Sam Godsiff
Rachel Henderson
George Legget
Chris Matthews
Bobby Richards

For Fletcher Systems

1. Executive Summary

The aim of this project is to design a fully functional kinetic sculpture that moves in strong winds yet returns to a motionless pillar, appearing solid and unyielding, in no wind. The project aims to deliver a scaled model of the kinetic sculpture along with the relevant documentation for the design of the full-scale sculpture.

The project is currently on track to a successful outcome. Prototype 1 was built as a proof of concept for the project, which was followed by background research into relevant areas of design for the sculpture. A second prototype was proposed and is in the process of being built. This is to allow testing of the mechanisms involved in the movement of the fins to ensure they provide a full 360° unconstrained range of motion. Initial design concepts were considered and a design consultation with Bruce Robertson lead to the proposal of a fully composite monocoque structure.

The focus for the project going forward is to test prototype 2 to find a return mechanism that will allow the desired motion. The sculpture frame and connections will be designed in parallel to increase efficiency of resources, so the build may begin as soon as possible. A testing rig will be employed to determine the required number of layers of carbon fibre composite for the final prototype. The team is on track to begin the testing of the final prototype on the 21st of August and deliver the final report on the 7th of October.

The key risk for the project is that manufacture of the frame will fall behind schedule and reduce the time that can be spent testing the final prototype.

2. Table of Contents

3. Introduction

The objective of the Kinetic Pillar Sculpture Project is to design and construct a fully-functional prototype that moves in the wind yet returns to a motionless pillar, appearing strong and unyielding in the absence of wind. The sculpture is designed to meet the required design specifications and have an aesthetically-pleasing visual impact. This mid-year report has been prepared to update Fletcher Systems on the project progress and highlight the key achievements, schedule issues and costs regarding the project to date. The report also contains information on upcoming milestones and outlines the potential risks to the project.

Figure 1: Initial animated designs of Kinetic Pillar by Fletcher Vaughan

4. Achievements

4.1. Prototype 1

In order to investigate the possible movement and structure of the Kinetic Pillar, an initial prototype was manufactured, as seen in Figure 2. Due to symmetry within the sculpture, only one "side" of the sculpture was constructed. Low density polystyrene and duct tape were used for the fin construction, with metal rods and plastic sleeves as "bearings". Metal elements were used to add counterweights to the fins, allowing for the fins to return to their original upright position from a near 90° angle of rotation. Compressed air was used to simulate wind affecting the sculpture. Although the prototype used commonly found materials, it provided an approximation of the actual movement of the sculpture and identified several potential design issues to consider. The prototype was a successful proof of concept.

Videos of Prototype 1 operating:
https://www.youtube.com/watch?v=Y0ievY-9q8o
https://www.youtube.com/watch?v=R_njphg_B7U

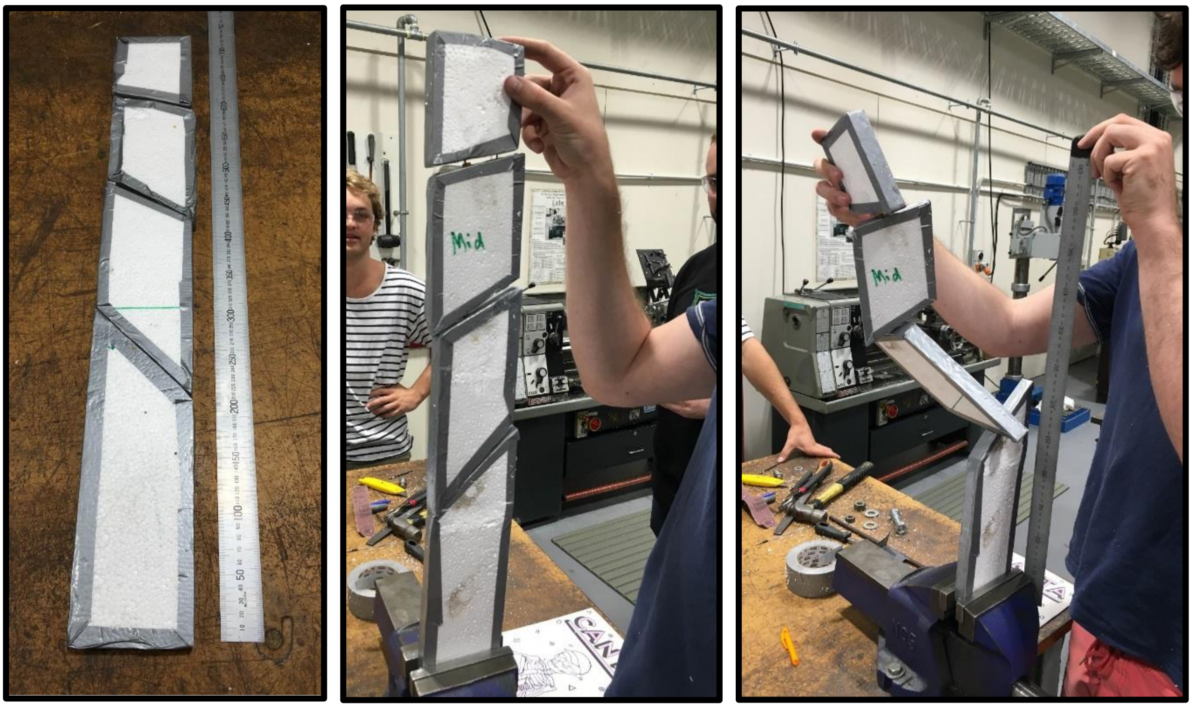


Figure 2: Kinetic pillar sculpture prototype 1 - concept validation

4.2. Background Investigation

Four main design and function categories were identified:

- Sculpture Frame
- Sculpture Materials
- Connections/Movement
- Return Mechanisms

Brainstorming sessions and research, along with our established background knowledge of sculptural design, allowed for several concepts to be generated for each category. Research into these categories was conducted individually and the ideas that were generated were then evaluated. The results of this research can be seen in Appendix A – Research.

4.3. Concept Evaluation

Evaluation matrices were initially utilised to evaluate the concepts for the design elements specified in the background investigation and are located in Appendix B – Evaluation Matrices. The highest ranking concepts indicated the best solutions for the design.

- Sculpture Frame – 'A' frame with struts and stringers (updated to monocoque design)
- Connection/Movement – Ball bearing system
- Sculpture Materials – Carbon fibre composite
- Return Mechanisms – Counter-weights (further investigation on-going)

One of the priorities in the design of the Kinetic Pillar was that the sculpture return to a static form when there is no wind. The movement of the sculpture is very important in realising the project vision and hence further development and evaluation of the return mechanisms was required. A second prototype was therefore planned to allow for the testing of counterweights, torsional springs, magnets or a combination of these return mechanisms.

4.4. Frame Development

An aluminium frame design was initially proposed for the base of the model. This initial design used an outer frame that was welded together. The interior of the frame housed struts with stringers running through them, in the same design as an aeroplane wing [1]. The initial design can be seen in Appendix G – Conceptual Design Models, Figure 11. This design was modified when further research showed that aeroplane wings buckle easily when an axial load is applied. The design was modified to utilise cross members to support the outer frame in the axial direction, with the stringers running through them to provide strength during a frontal wind load. The updated design also utilised a carbon fibre shell that could be bolted to the frame for ease of access to the interior parts, which can be seen in Figure 12.

After a consultation with Bruce Robertson (UC Technical Services Officer) it was decided that the stringers were not necessary as the internal cross beams would provide sufficient strength to the design. It was concluded that if a carbon fibre shell was already being produced, it would be more efficient to construct the entire structure from carbon fibre in a monocoque style design. Thus the frame design was updated, creating a low weight and high strength structure with the desired aesthetic properties. To accommodate the bearings and shafts required for the movement of the structure, a cartridge style system was proposed to allow the bearing housing to be installed after the construction of the sculpture body.

4.5. Detailed Design

4.5.1. Wind Loading

To determine the forces that would be applied by the wind to the structure when in its upright pillar position the wind standard AS/NZS 1170.2 2011 was consulted [2]. The relevant calculations can be seen in Appendix B. Due to the unknown final location of the sculpture, assumptions were made to simulate a realistic scenario whilst trying to maintain a consideration for a worst case. A once in 50 year event was chosen as the starting wind speed, using the highest wind speed zone in New Zealand and assuming the structure was not in a specified 'lee' zone. The lack of openings into the structure significantly reduced the complexity of the standard, allowing the sculpture to be classified as a free standing wall. As the design of the internal structure had not been finalised, the dynamic response factor was assumed to be 1, with the intention to reassess the final loads on the structure after finalising the design. The design wind speed was found to be 129 m/s, which produced a design pressure of 238 Pa and a force of 1189 N acting on the sculpture. This force will be subject to change after finding the fundamental frequency of the sculpture, which will affect the dynamic response factor.

4.5.2. Carbon Fibre Testing

Following the determination of the wind loading on the kinetic pillar structure, the detailed design of the structure itself could take place. It was determined from the concept evaluation matrices that a suitable material would be carbon fibre composites. Further consultation with Bruce Robertson and the client confirmed that this would be the optimum concept to explore for the final solution. Material testing will be carried out on flat sheets of carbon to determine material properties. Further details of the testing and design can be seen in Appendix D – Carbon Fibre .

4.6. Prototype 2

The goal for prototype 2 was to facilitate a study of the movement of the sculpture, while maintaining a simplistic and low cost design. Wood was used as a framing material taking advantage of its availability and forgiveness as a building material. Skateboard bearings were used to give the sculpture rotation with an 8mm rod as a pivot axis for the fins. Steel collars attached the fins to the rods leaving a gap of 15mm between fins. The prototype was designed to allow the calibration of the counterweights to give the intended movement. The design will allow the option to add different mechanisms to assist the movement and ensure a continuous organic 360° range of motion is achieved. Additional information and images of the on-going construction of the prototype are located in Appendix A.

5. Schedule

The project has kept closely to the schedule as outlined in the project proposal. Going forwards, the design of the connection mechanisms will be finalised after the testing of the second prototype. This will ensure the sculpture has an unencumbered motion. The change in design to a carbon fibre monocoque design from the initial aluminium design as well as the other stated factors have slightly delayed the design phase of the project and moved back the build phase. This is visible in the attached Gantt chart in Figure 10, Appendix F – Gant Charts.

To achieve the results required by the client, work streams will be run simultaneously to increase the efficiency of the team’s resources and time. By designing the bearing housings and shells in tandem, the designs will be able to evolve in a complimentary fashion. The initial design of the monocoque frame does not require the material properties of the carbon fibre to be known exactly, allowing the material testing to be carried out at the same time as the design process. In the same way the connection and movement mechanism can be designed simultaneously with the testing of the second prototype. The build time of the final prototype will depend on the time the team will be able to acquire in the composite workshop and the number of carbon fibre layers in the monocoque construction. The testing of the final prototype may depend on the weather as final outdoor testing will require a day with sufficient winds. The team is confident that the project will remain on schedule.

6. Costs

There has been some re-allocation of costs but the total budget has remained unchanged. Please refer to Appendix H – Costs for more in-depth costing details.

7. Risks and Issues

Looking forward, there are several potential concerns regarding the design. The proposed thickness of 150mm in the base tapering down to 30mm at the peak could pose a challenge to fit in all the internal components. The internal frame and 12 bearing housings are required to fit inside the sculpture to allow the fins to rotate. The size and the weight of the fins will be studied to find the loading on the bearings. This loading will determine the size and type of bearings used. A potential concern is that the outer bearing dimensions will be outside the constraints of the frame.

The intended motion of the sculpture is to stand as an unyielding pillar during light winds and to ‘dance’, with seemingly random motion, during stronger winds. When there is consistent medium wind there is potential for the sculpture to open out and be held in an open position with the fins at an angle of least resistance to the wind as shown in Figure 3. Further research using prototype 2 will be undertaken to keep the sculpture dancing rather than stationary.

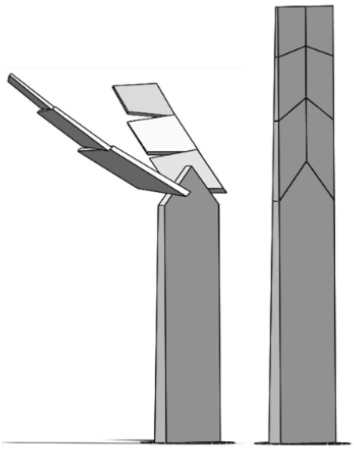


Figure 3: Potential low- medium wind configuration

Because the design incorporates moving internal parts there will need to be a method for maintaining the bearings within the structure. The sculpture should have no obvious openings or fasteners so it will require an innovative way to access the bearings and shafts of the fins. Another concern is how to stop the motion of the fins for maintenance. If the fins are still moving it could be dangerous to approach the sculpture. Locking mechanisms and other safe ways to stop the movement will be explored.

8. Next Steps

8.1. Project Plan

The following work streams include the remaining and updated sub-tasks required for successful completion of the project. These will be focused on and completed by the milestone dates outlined. The timeline for the second half of the project can be seen in Appendix F – Gant Charts, Figure 10.

8.1.1. Prototype 2

- Complete construction
- Test to evaluate return mechanisms

8.1.2. Detailed final Design

- Design carbon fibre monocoque
- Design fin connections
- Modelling (CAD, CAE)

8.1.3. Manufacture

- Test carbon fibre sheets for material property testing
- Construction of final prototype

8.1.4. Testing

- Test final prototype in real-world conditions

8.1.5. Final Design Documentation

- Working drawings
- Final report

**Note: Some identified work streams will run simultaneously.*

8.2. Milestones

Table 1: Milestone achievements and expected dates

Milestone	Completion Date
Prototype 2 Testing Complete	5th June
Detailed Final Design	21st June
Manufacture Completed	20th August
Testing Completed	9th September
Final Design Completed	7th October

9. Contribution Statement

Sam Godsiff: Built prototype 1 and prototype 2 with the team. Worked with G.L and R.H on the wind loading calculations and the investigation into composite construction by talking to the Formula SAE team. Worked on evaluation tables with G.L and B.R. Designed the initial frame concepts, researched potential dampeners and developed the project timeline with R.H. Attended all meetings with the supervisor and client and developed work streams for the team.

Christopher Matthews: Researched the movement solutions, project risks, testing methods, concepts, use of torsional springs, wind standards and low speed wind tunnel testing. Present for all meetings with supervisor and client. Wrote up work streams and risks in proposal. Problem solving for design issues such as return mechanisms. Tested prototype one, visited UC SAE carbon fibre chassis team in Auckland and initiated communications between teams. Conceptualised and designed prototype 2 with B.R. Sourced and ordered materials and manufactured prototype with B.R and S.G.

Rachel Henderson: Researched the project background and produced conceptual designs. Developed DRS, scope and timeline (with S.G). Developed design concepts and researched movement solutions for sculpture. Researched and performed wind loading calculations and built prototype 1 and 2 with team. Investigated carbon fibre manufacture with UC SAE Team. Contributed to proposal and mid-year report, attended meetings and managed communications with sponsor.

Bobby Richards: Involved with concept generation and evaluation matrices for materials, pivot types, return mechanisms and frame types alongside G.L and S.G. Produced designs for prototype 1 with S.G and constructed/tested prototype 1 with the team. Worked on the introduction and specifications for the proposal and attended all meetings with supervisor and client. Researched magnets and types of bearings. Worked with C.M to conceptualize and design prototype 2 and helped/managed the construction of prototype 2.

George Legget: Researched project background and investigated similar sculptures, leading to concept generation and evaluation matrices completion (materials, return mechanisms, frame structure, connection and movements). Developed budget and researched materials solutions for the sculpture. Organised meetings with Formula SAE team and Oracle Team USA (previous employer) for carbon-fibre composites application in sculpture leading to monocoque conceptualisation. Assisted with construction of prototypes 1 and 2. Completed wind loading calculations with S.G and R.H. Contributed to proposal and mid-year report and attended all meetings with project supervisor and client.

10. Conclusion

The project aim of completing a full scale kinetic sculpture is on target to be completed on the 7th of October. Research has been undertaken to explore different materials and internal framing as well as methods for returning the sculpture to its upright pillar state. To date, an initial prototype has been successfully completed and tested. Concepts have been developed and evaluated to determine the best solutions for the design. Testing of carbon fibre composite panels will take place in parallel with the development of movement methods using prototype 2. This will enable the team to determine the key loads on the sculpture and to produce relevant design documentation for the full size model. The one metre scale model will demonstrate all of our research and learning to date and is scheduled to be completed on time.

The Kinetic Pillar Sculpture team is committed to achieving the vision of Fletcher Systems and is confident that their research and investigations will lead to a successful outcome. The risks to the completion of the project have been identified and will not prevent the realisation of an uncompromised sculptural design.

11. Appendices

Appendix A – Research

Background Research on Kinetic Sculptures

Research was conducted to discover how a comparable kinetic motion was achieved in similar wind powered works by artists such as New Zealander Phil Price, American Modernist George Rickey, Aiko Groot and Len Lye. A selection of these comparable sculptor's works can be seen in Figure 4 and Figure 5. A particular emphasis was placed on achieving the motion through unassisted wind power in the research. Research into suitable materials with the necessary properties of strength and lightness was completed. A number of potential frame designs were proposed and investigated for their ability to support both lateral wind support loads and vertical axial self-weight loads. This was also pondered for the mechanisms to achieve movement and support in terms of rods and bearings.

Notably, Phil has combined composite materials, wing shaped blades and precision materials to create a unique art form with unpredictable kinetic motion.

Figure 4: Left: Phil Price's "Quattro" [3], Middle: Aiko Groot's "Discs" [4], Right: Len Lye's "Wind Wand" [5].

Figure 5: Left: Phil Price's "United Divided" [3], Middle: Phil Price's "Cellular" [3], Right: George Rickey's "Two Open Triangle Leaning II" [6].

Magnetorheological Fluid

Magnetorheological fluid is a fluid that contains particles that can be manipulated through the use of a magnet. When a magnetic field is applied to the fluid the particles within it change their viscosity, which can be manipulated depending on the strength of the field applied. To run such a device, electromagnets are used to produce a variable strength field that can be manipulated quickly with an electronic controller. This type of fluid is commonly used inside a dampener to give a variable dampening ability, which is very useful in cars and other moving assemblies. This type of dampener was considered as a method to lock the sculpture during high winds as it could be controlled electronically or remotely.

Electrorheological Fluid

An electrorheological fluid is a fluid that contains particles that will affect the viscosity of the fluid when in the presence of an electric field. The viscosity of such a fluid can increase in the order of up to 100,000, making it an ideal fluid to use in variable dampeners, shock absorbers and brakes. One problem with an electrorheological fluid is that the particles will fall out of suspension over time unless the density of the particles and the fluid are the same, making it less reliable but cheaper than a magnetorheological fluid.

Possible Return Mechanisms

The initial solution to make the sculpture return to its original position in no wind was to utilize weights and create moments around the point of rotation for each fin. This return mechanism was used in the first prototype, during which it became clear that the weights caused a high level of axial loads on the rods connecting the fins. Because of this it was decided that ways of minimizing the weight should be explored.

Possible solutions, such as torsional springs, magnets and ball and socket joints, were conceived. Torsional springs have the advantage of not only being able to reduce the amount of weight needed in the moments but also to dampen the movement which would achieve the fluid movement that the client wants to achieve [7] [8].

Several companies were found which were capable to produce springs to the specifications that are needed [9]. Two of the companies were located in North America and one in Wellington. The relevant equations and instructions to hand build the springs were also located.

Magnets can be utilized to help the fins retract the final couple of degrees when returning to the original positions, it also prevents the sculpture being slightly deformed, yet static, in low winds.

Ball joints, similar to medical applications of “Ball and Socket” joints, were explored as potential connection mechanisms between the fins [10]. The joints allow movement in two planes simultaneously, including 360° rotation [11], [12]. However, the ‘side-to-side’ movement of the fins allowed by a standard ball joint would complicate the sculpture design and possibly cause fin collisions.

Utilising Carbon Fibre Nomex

A meeting with the University of Canterbury’s Formula SAE team, whilst they were in Auckland, allowed for carbon fibre to be further investigated. The SAE team were manufacturing a car chassis out of carbon fibre and Nomex, a material with a honeycomb-structure. Nomex is extremely strong in one direction and very easy to crush perpendicular to this direction. During the meeting it was demonstrated how the carbon fibre was measured and cut as well as the process of utilizing an auto clave to transform the fabric into its final form. This meeting provided options to consider in terms of ways to strengthen the structure. Valuable relationships were also established with high ranking SAE team members who have offered their advice and carbon fibre off-cuts for testing.

Prototype 2

The design process gave an insight into unforeseen difficulties with the sculpture design and construction such as fin thickness when trying to mount bearings. It was also found that the fins are crowded with components internally and careful considerations will be need to be made for the final design.

Sockets were placed for magnets to sit in the outside tip of each fin and allowed room for a torsional spring to be added on top of the bearing. A study will be carried out to see the effects these components have on the movement of the sculpture, possibly giving it a more random ‘dancing’ motion. The solution was to have a simple hook where weights could be hung off.

For the pivot mechanism we used three types of connections in each fin using a collar, bearing or both. The top connection joins the fin to the rod using a collar and a grub screw to hold it in place as shown in the left of Figure 6. The middle image of Figure 6 is the lowest connection and uses a bearing to hold the rod in place, while still allowing it to rotate. The middle fin connection uses a collar-bearing combination so the adjacent fins can rotate separate to one another shown in the right of Figure 6. The middle connection also has an area for a torsional spring to be installed above the bearing around the base of the rod.

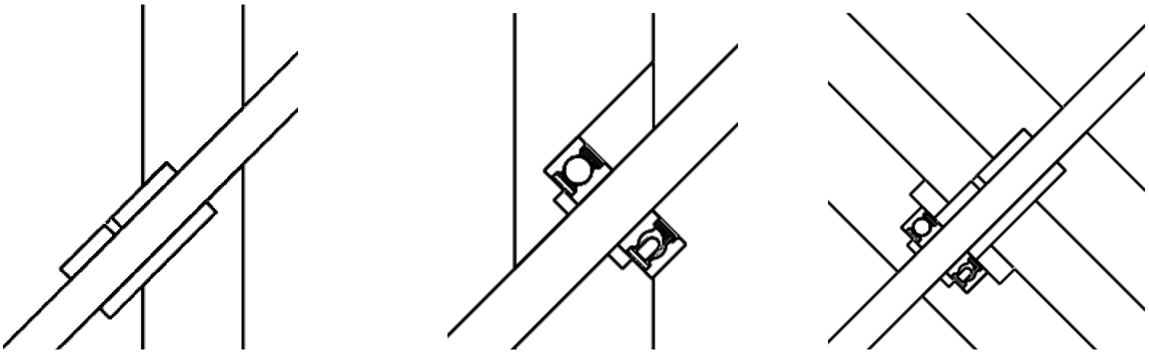


Figure 6: Left: Collar to hold the shaft in place, Middle: The bearing holding the shaft in place, Right: Bearing and collar combination.

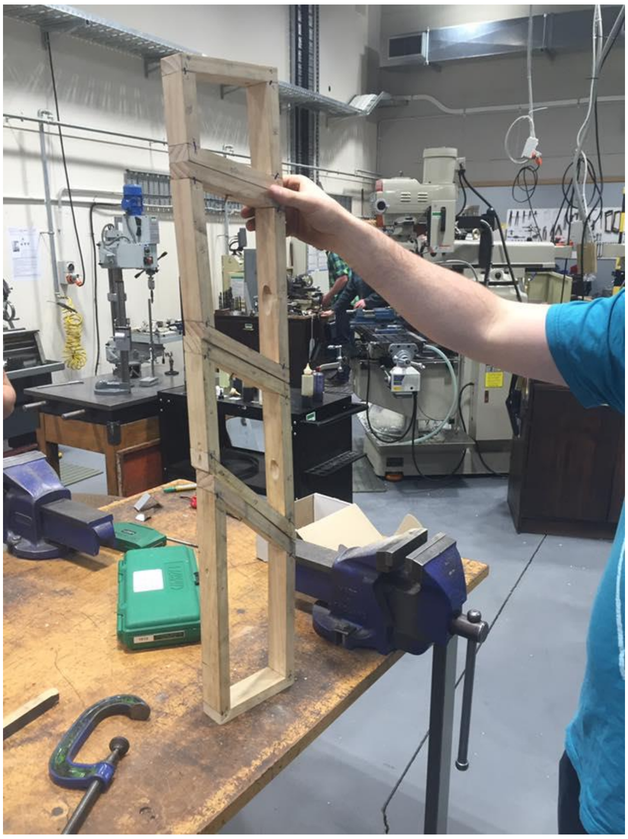


Figure 7: On-going construction of prototype 2

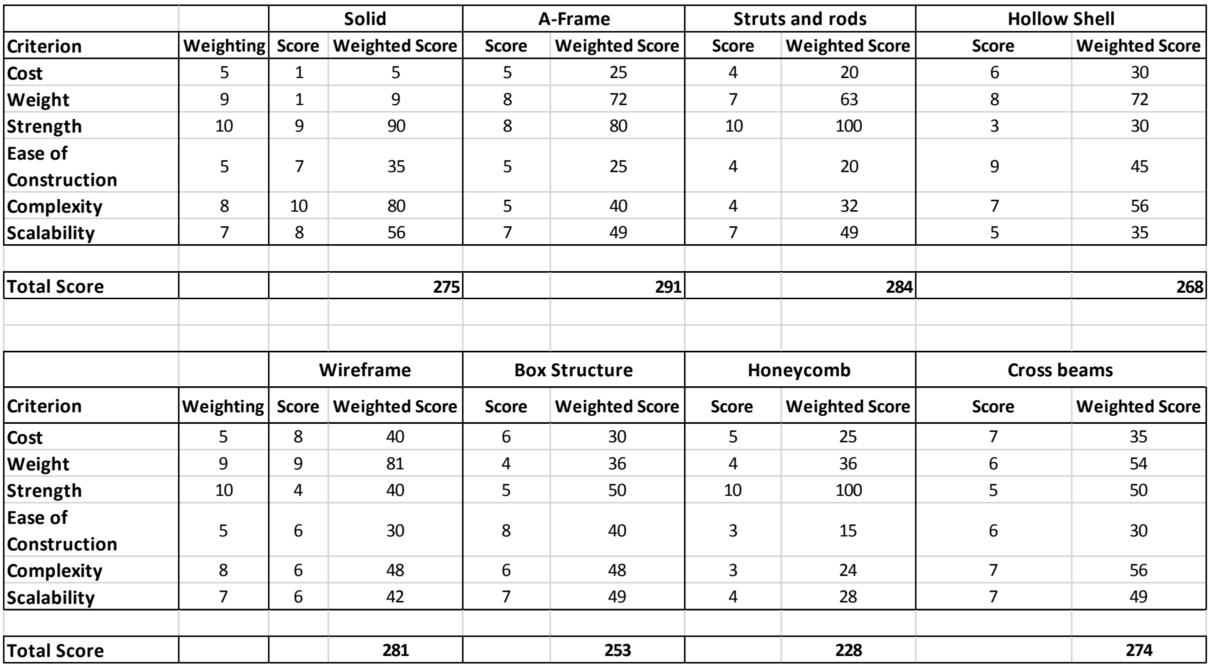
Appendix B – Evaluation Matrices

Frame

To evaluate which initial frame design would be the best for the base and fins an evaluation matrix was used to produce weighted scores. It was found through this evaluation shown in Table 2 that an A frame, struts and rods (stringers) and a wire frame would be the best options for the frame design. The frame strength and weight were considered the most important criteria.

**Note: This evaluation was carried out before the design consultation with B.Robertson.*

Table 2: Evaluation table for the frame



		Solid		A-Frame		Struts and rods		Hollow Shell	
Criterion	**Weighting**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Cost	5	1	5	5	25	4	20	6	30
Weight	9	1	9	8	72	7	63	8	72
Strength	10	9	90	8	80	10	100	3	30
Ease of Construction	5	7	35	5	25	4	20	9	45
Complexity	8	10	80	5	40	4	32	7	56
Scalability	7	8	56	7	49	7	49	5	35
Total Score			**275**		**291**		**284**		**268**

		Wireframe		Box Structure		Honeycomb		Cross beams	
Criterion	**Weighting**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Cost	5	8	40	6	30	5	25	7	35
Weight	9	9	81	4	36	4	36	6	54
Strength	10	4	40	5	50	10	100	5	50
Ease of Construction	5	6	30	8	40	3	15	6	30
Complexity	8	6	48	6	48	3	24	7	56
Scalability	7	6	42	7	49	4	28	7	49
Total Score			**281**		**253**		**228**		**274**

Movement and Support Systems

When evaluating possible movement and support structures, the most important factor was the strength of the component, because in the kinetic pillar sculpture the movement and support systems will to be subjected to high levels of axial and radial stress.

Cost was weighted as the second most important factor. This is because of the budget that the project is constrained by. A large proportion of the budget will be spent on expensive materials like carbon fibre. If spending can be reduced in other areas then this will be explored.

The third most important factors are the durability and maintenance. Because the final location for the sculpture is unknown, it is within the projects best interests that their sculpture be made as durable as possible and easy to maintain.

Through using the evaluation matrix it was decided that ball bearings would be the best system to use. It scored an average of 8 across the criteria, with the highest score being 9/10 for both availability and complexity and the lowest score being 7/10 for strength. If ball bearings are used in the final design, spherical roller bearings will be investigated to support the high axial and radial loads. Coincidently, the spherical roller bearing was rated as the second best concept. It scored an approximate average of 7.5/10 with the lowest score being 5/10 for maintenance. The bearing concept selection is still subject to re-evaluation after the loads have been established.

Table 3: Evaluation table for the movement and support mechanism

		Thrust bearing		**Gliding bearing**		**Needle Bearing**		**Ball bearing**	
Criterion	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Cost	9	7	63	5	45	6	54	8	72
Weight	7	6	42	6	42	6	42	8	56
Strength	10	8	80	10	100	7	70	7	70
Ease of Construction/integration	5	8	40	8	40	7	35	8	40
Durability	8	7	56	8	64	7	56	8	64
Operational Lifetime	7	7	49	8	56	6	42	8	56
Availability	7	7	49	6	42	8	56	9	63
Complexity	5	5	25	5	25	8	40	9	45
Maintenance	8	5	40	7	56	6	48	6	48
Total			**444**		**470**		**443**		**514**

		Spherical Roller bearing		**Ball and Socket**		**Rollers**	
Criterion	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Cost	9	7	63	5	45	9	81
Weight	7	7	49	5	35	8	56
Strength	10	8	80	8	80	4	40
Ease of Construction/integration	5	8	40	7	35	6	30
Durability	8	8	64	6	48	7	56
Operational Lifetime	7	8	56	6	42	7	49
Availability	7	8	56	5	35	8	56
Complexity	5	6	30	4	20	8	40
Maintenance	8	5	40	6	48	5	40
Total			478		388		448

	Order	**Total**
1	Ball bearing	514
2	Spherical Roller bearing	478
3	Gliding Bearing	470
4	Rollers	448
5	Thrust bearing	444
6	Needle Bearing	443
7	Ball and Socket	388

Return Mechanisms

The potential return mechanisms were considered and evaluated. The durability of the mechanisms were assigned the highest criterion value as this trait was considered the most important for the outdoor, cyclic application. The strength, ease of construction and maintenance criterion were also highly weighted as the sculpture return mechanism needed to easily integrate into the design and be low maintenance. The concept of using weights in the fins scored highly in the heavily weighted criteria but, as expected, would increase the sculpture weight and scored low in the weight and strength/power category. Weighted fins were ranked the best concept. However, there was only a slight difference in the scores for torsional springs, coil springs and magnets.

Table 4: Evaluation table for the return mechanism

		Torsion spring		Coil Spring		Magnets		Weights		Elastic Materials	
Criterion	**Weighting**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Cost	7	8	56	6	42	4	28	9	63	8	56
Weight	6	8	48	5	30	6	36	2	12	8	48
Strength/Power	9	7	63	7	63	4	36	4	36	7	63
Ease of Construction/integration	9	8	72	8	72	9	81	8	72	6	54
Durability	10	7	70	8	80	8	80	9	90	7	70
Operational Lifetime	7	6	42	8	56	8	56	9	63	5	35
Availability	5	7	35	9	45	9	45	9	45	9	45
Complexity	6	8	48	6	36	9	54	9	54	8	48
Maintenance	8	6	48	7	56	8	64	8	64	7	56
Total			**482**		**480**		**480**		**499**		**475**

Materials Evaluation

The ease of construction for the components and how they would be manipulated if they were included in both the prototypes, scale model and full size sculpture (by both unskilled and skilled technicians) was given an 80% weighting.

Due to the fact that the team were confined to a budget of around $3000, the cost of the selected material was given consideration with a weighting of 70%. We are committed to delivering the scale model to within a reasonable cost and must also ensuring the costs associated with construction of the full size sculpture will allow a margin of profit to be made for the sculptor.

The weight of the structure needed to be considered carefully to achieve the desired motion of the artist through pure wind power. The structure must be sufficiently strong to support both its own self weight as a static and dynamic pillar, the lateral wind loads on its face (which can be in excess of $45ms^{-1}$) and also the axial load of the fins above. It must also be constructed to withstand the rotating moments that are produced at each of the shafts. The concept of incorporating additional weights on the inside of the frame to create righting moments dictated that the structure must be both lightweight and strong. The weight of the materials was therefore given an importance of 80%. Without the necessary material strength in the part it will be very difficult to achieve the rigid appearance of the sculpture whose fins must have minimal deflection. The material should be as stiff as possible to absorb the maximum amount of force from the wind that powers it in order to achieve an unpredictable yet precise motion. The strength of the selected material was given a 100% weighting accordingly.

It was determined that in order for the sculpture to maintain the desired appearance and also its critical functions to operate precisely and safely it would need to be sealed from the elements. It was highlighted that possible issues could arise with maintenance and posed the question of how the necessary refill of lubricants or grease nipples was to be achieved, without compromising weather protection elements or areas that needed to be shielded from the elements. Weather resistance was given a weighting of 80% accordingly.

The design also needed to incorporate safety factors to ensure the safety of nearby people or animals and also to minimise the negative environmental effects of the sculpture over its entire life cycle of 20+ years. Safety was given a weighting of importance of 70% in the evaluation matrix for the materials selection. The materials to be employed in the prototypes needed to be readily available for immediate incorporation in the build cycle. The larger amounts of material needed for the final prototype and finished sculpture could be allowed to have a longer league time to order. The availability of materials was given a weighting of 40%. The goals of achieving the desired motion and appearance was of more importance than the complexity of the design. For this reason the complexity factor was given a weighting of 30%.

Given the special case of our project being a sculptural design, the material components of the final design outcome must be highly functional but also exceptionally aesthetically pleasing. Therefore the weighting factor for the material's aesthetic properties was determined to be 100%.

Table 5: Evaluation table for the materials

Materials Evaluation																
		Plastic		Fiberglass		Aluminium		Carbon Composite		Wood		Clysar		Sail Cloth	
Criterion	**Weighting**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Cost	7	7	49	6	42	5	35	3	21	8	56	5	35	9	63
Weight	8	4	32	5	40	6	48	9	72	4	32	10	80	8	64
Strength	10	6	60	7	70	7	70	9	90	5	50	3	30	5	50
Ease of Construction	8	5	40	4	32	7	56	3	24	9	72	5	40	8	64
Weather Resistance	8	6	48	6	48	9	72	8	64	6	48	4	32	7	56
Operational Lifetime	7	6	42	5	35	9	63	7	49	8	56	4	28	6	42
Availability	4	8	32	8	32	8	32	6	24	10	40	6	24	7	28
Complexity	3	4	12	5	15	6	18	3	9	9	27	6	18	8	24
Maintenance	6	9	54	5	30	8	48	7	42	5	30	5	30	5	30
Aesthetics	10	6	60	7	70	7	70	10	100	5	50	6	60	7	70
Total			**429**		**414**		**512**		**495**		**461**		**377**		**491**

Appendix C – Wind Loading Calculations

$$V_R = V_{50}\ for\ region\ B$$

$$V_{50} = 48\ ms^{-1} \quad For\ a\ one\ in\ 50\ year\ event$$

$$Wind\ multiplier : M_a = 1.0$$

$$m_{z1cat} \rightarrow category\ 1\ for\ a\ conservative\ result$$

$$height \geq 5m \ : \ m_{z1cat} = 1.05$$

$$Assume\ no\ shielding: m_d = 1.0$$

$$Lee\ multiplier = 1.35$$

$$wcs: on\ crest\ of\ hill \rightarrow upwind\ slope \geq 0.45$$

$$m_h = 1.71$$

Section 5

$$Aerodynamic\ Shape\ Factor$$

$$Assume\ no\ internal\ pressures.$$

$$(c)\ Free\ standing\ wall$$

$$C_{Pn} = 0.03$$

$$k_a = area\ reduction\ factor = 1.0$$

$$k_\ell = local\ pressure\ factor \quad => a = 0.15 \times 0.2 = 0.03$$

$$0.25a^2 = 0.000225 \qquad A = 5\ m^2 \qquad A \gg 0.025a^2$$

$$k_\ell = 1.0$$

$$k_p = permeable\ cladding\ reduction\ factor$$

$$The\ material\ is\ not\ permeable \quad => \quad k_P = 1.0$$

$$C_f = \ f\ (frictional\ drag)$$

$$\frac{d}{h}, \frac{d}{b} < 4 \quad => f\ (frictional\ drag) not\ required$$

$$C_{fig} = C_{P1n} k_a k_\ell k_P \quad (pressure\ normal\ to\ surface)$$

$$C_{fig} = 0.03 \times 0.8 \times 1 \times 1 = 0.024$$

Section 6

$$h = 5\ m \quad I_z 0.165\ for\ (TCI) \quad S = 2.5\ m \quad b_{sh} = 1\ m$$

$$L_h = 85 \left(\frac{h}{10}\right)^{0.25} \qquad = 71.47$$

$$B_s = \frac{1}{1 + \frac{\sqrt{0.26(h-s)^2 + 0.46b_{sh}^2}}{L_h}} = 0.98$$

$$H_s = 1 + \left(\frac{s}{h}\right)^2 = 1.25$$

Appendix D – Carbon Fibre Construction

Testing

The specific material properties of carbon-fibre composites are difficult to determine in theory, as unlike metallic materials, they are not isotropic. Following consultation with the University of Canterbury Motorsport Formula SAE racing team, who have significant experience with composite construction, it was decided that it would be best to manufacture and test some flat carbon panels to get a gauge of the properties of the material. They will be constructed in the composites workshop and analysed in a purpose built testing rig. It will be very valuable to know the deflection, stress and strain performance of the flat panels when loaded laterally (on the large flat face) and also axially (on its short edge). Due to the tall and slender nature of the design, it is important that buckling is considered as a mode of failure and is accommodated for in the overall design.

Construction

A fully composite design consisting of several layers of wet-laminated carbon fibre externally in combination with a foam core for strength in multiple directions would be constructed. A flange would be constructed to create an external seal and a taping layer would be applied to ensure a flat appearance at the edges of the structure. Aluminium core may also be incorporated in areas that need significantly more strength. Figure 8 is a hand sketch of the construction method.

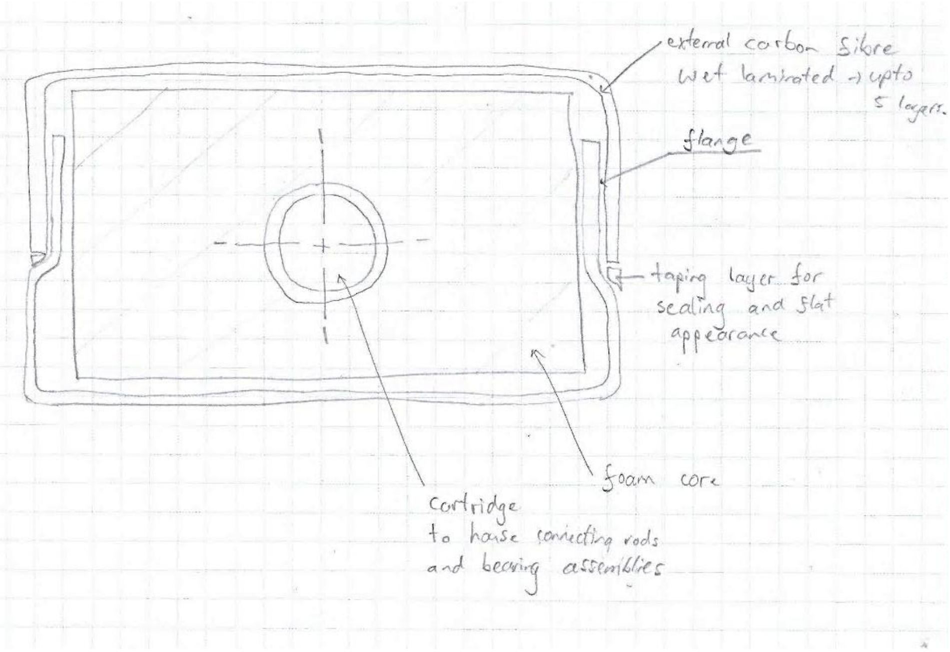


Figure 8: Free sketch detailing the carbon fibre monocoque construction

A mould will be created out of flat MDF wood panel and the dry fibre will be wet-laminated with epoxy resin and cured overnight. Several panels will be made with a single layer, three layers, five layers and seven layers of carbon fibre weave. The deflection and stress-strain data that will be recorded from the testing of these pieces will then be used for detailed design of the overall monocoque design. An informed decision will be able to be made on how many layers the carbon shell should comprise of for each of the elements. Further testing will also be undertaken to determine the performance of the structure when the foam core is incorporated. The team will also endeavour to keep the construction method and environment as constant as possible to minimise variability in the material properties that could affect the overall sculpture performance.

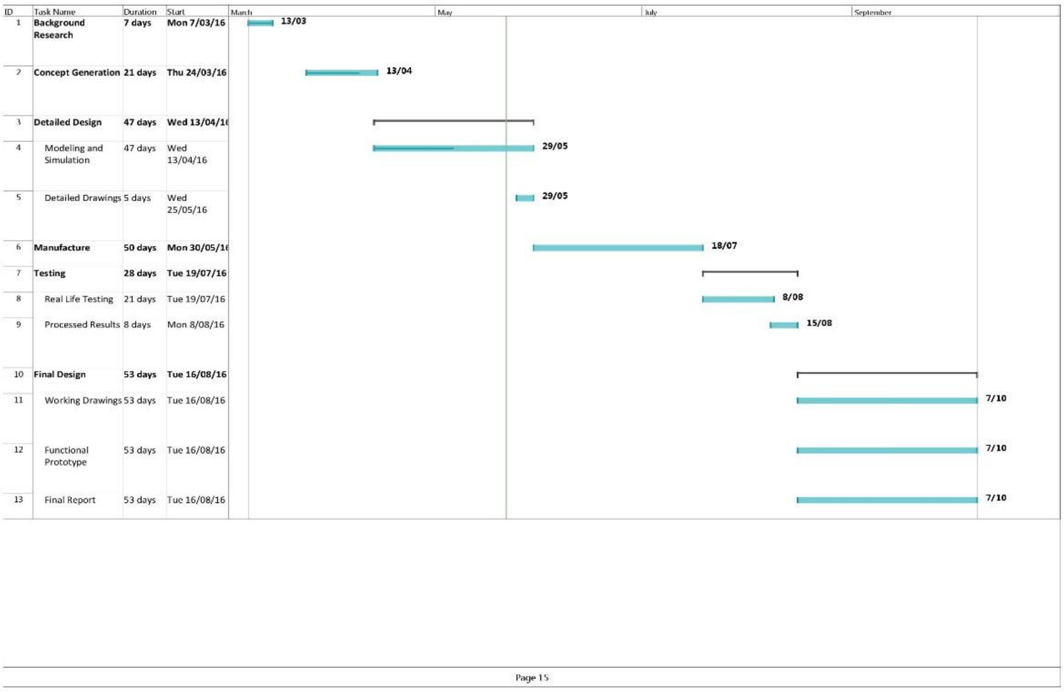
Appendix E – Design Requirement Specifications

Table 6: Design requirement specifications

<table>
<tr><td colspan="6">DESIGN REQUIREMENT SPECIFICATION</td></tr>
<tr><td colspan="3">Sponsor: Fletcher Systems
Design Team: Sam Godsiff, Rachel Henderson, George Legget, Chris Matthews, Bobby Richards
Supervisor: John Pearse</td><td>Final Year Project: Kinetic Pillar Sculpture</td><td colspan="2">Issue Date: 4/3/2016</td></tr>
<tr><th>Requirement Category</th><th>D/W</th><th>Wt</th><th>Requirements</th><th>Source</th><th>Modified</th></tr>
<tr><td rowspan="12">FUNCTIONAL</td><td>W</td><td>H</td><td>Dimensions (5500H x 1000W x 150D mm)</td><td>FV</td><td></td></tr>
<tr><td>W</td><td>M</td><td>Maximum weight of sculpture = 2000kg (to be carried by truck)</td><td>RH</td><td></td></tr>
<tr><td>D</td><td></td><td>Wind causes sculpture limbs to disengage and swing</td><td>FV</td><td></td></tr>
<tr><td>W</td><td>H</td><td>In absence of wind, sculpture returns to initial shape/form</td><td>FV</td><td></td></tr>
<tr><td>D</td><td></td><td>Durable material</td><td>RH</td><td></td></tr>
<tr><td>D</td><td></td><td>Designed to operate in outdoor conditions with severe weather conditions as defined in applicable AS/NZS standards</td><td>RH</td><td></td></tr>
<tr><td>W</td><td>H</td><td>Designed to operate in wind velocities as specified in wind standard: AS/NZS1170.2</td><td>RH</td><td></td></tr>
<tr><td>W</td><td>H</td><td>Sculpture limbs to move at varying velocities</td><td>RH</td><td></td></tr>
<tr><td>W</td><td>H</td><td>Material able to be exposed to extended high UV levels.</td><td>RH</td><td></td></tr>
<tr><td>D</td><td></td><td>Sculpture foundation must be stable</td><td>RH</td><td></td></tr>
<tr><td>D</td><td></td><td>Design to provide protection from water freezing in crevices.</td><td>SG</td><td></td></tr>
<tr><td>D</td><td></td><td>If alternative power source is used it must be reliable</td><td>CM</td><td></td></tr>
<tr><td rowspan="2">SAFETY</td><td>D</td><td></td><td>No hazard to viewers</td><td>RH</td><td></td></tr>
<tr><td>D</td><td></td><td>Meets all applicable AS/NZS safety standards</td><td>RH</td><td></td></tr>
</table>

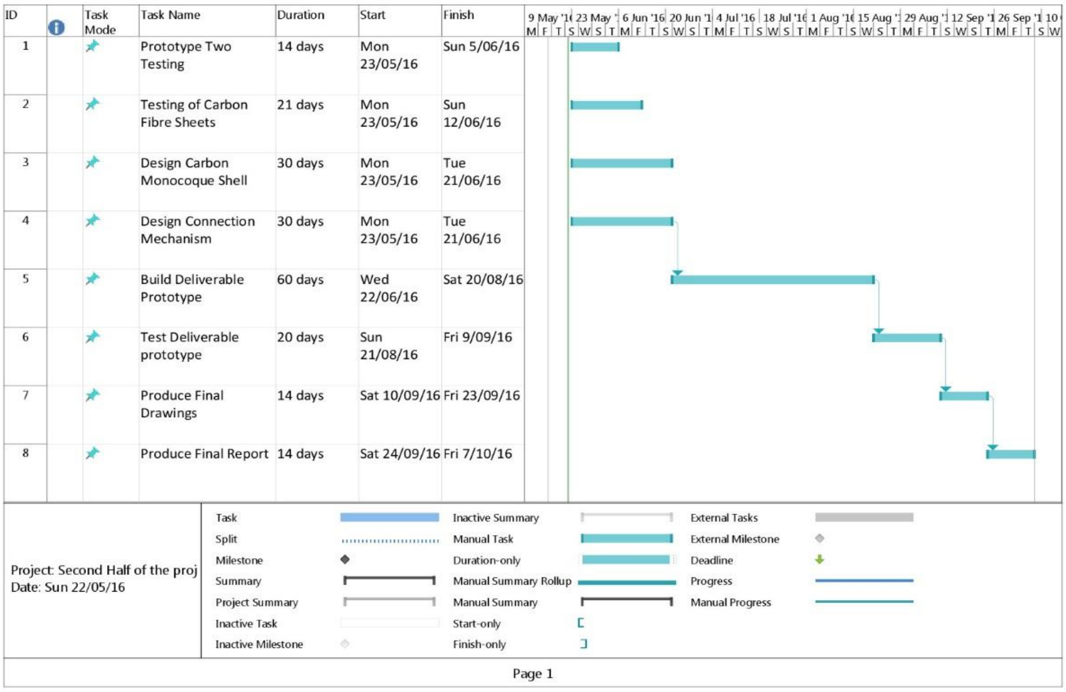
	D		Any electrical elements meet NZ/AUS regulations and standards.	RH	
	W	H	Locking mechanism for cleaning, repairs, extreme weather, etc.	BR	
QUALITY	D		Sculpture should have a working life for over 10 years	BR	
	D		Sculpture must operate at all times there is wind present	CM	
MANUFACTURING	D		Meet NZ manufacturing and safety standards.	BR	
	D		Parts must be strong enough to be transported long distances	CM	
TIMING	W	H	Final prototype delivered before the 7th November 2016	BR	
ECONOMICS	D		Sculpture maximum construction cost of $20,000	FV	
ERGONOMICAL	W	H	Sculpture able to be experienced from human eye-level (3 feet – 7 feet tall)	RH	
	W	H	Sculpture to pose no risk to 8 ft person standing next to it	RH	
ECOLOGICAL	D		Sculpture has minimal negative effect on surrounding environment including noise pollution	BR	
	W	M	Materials are eco-friendly	BR	
AESTHETIC	D		Sleek, mysterious, pleasant appearance	FV	
	D		Appears solid and unyielding when no wind is present	FV	
	D		Surprising movements when wind operates	FV	
	W	M	Materials don't hold dust, etc.	SG	
LIFE-CYCLE	W	H	Provides access for maintenance of sculpture components	SG	
	D		Will be accessible for cleaning	BR	
	D		Sculpture must be easily repaired	CM	

Appendix F – Gant Charts



ID	Task Name	Duration	Start
1	**Background Research**	**7 days**	**Mon 7/03/16**
2	**Concept Generation**	**21 days**	**Thu 24/03/16**
3	**Detailed Design**	**47 days**	**Wed 13/04/16**
4	Modeling and Simulation	47 days	Wed 13/04/16
5	Detailed Drawings	5 days	Wed 25/05/16
6	**Manufacture**	**50 days**	**Mon 30/05/16**
7	**Testing**	**28 days**	**Tue 19/07/16**
8	Real Life Testing	21 days	Tue 19/07/16
9	Processed Results	8 days	Mon 8/08/16
10	**Final Design**	**53 days**	**Tue 16/08/16**
11	Working Drawings	53 days	Tue 16/08/16
12	Functional Prototype	53 days	Tue 16/08/16
13	Final Report	53 days	Tue 16/08/16

Figure 9: Original Gant chart from the proposal



ID		Task Mode	Task Name	Duration	Start	Finish
1			Prototype Two Testing	14 days	Mon 23/05/16	Sun 5/06/16
2			Testing of Carbon Fibre Sheets	21 days	Mon 23/05/16	Sun 12/06/16
3			Design Carbon Monocoque Shell	30 days	Mon 23/05/16	Tue 21/06/16
4			Design Connection Mechanism	30 days	Mon 23/05/16	Tue 21/06/16
5			Build Deliverable Prototype	60 days	Wed 22/06/16	Sat 20/08/16
6			Test Deliverable prototype	20 days	Sun 21/08/16	Fri 9/09/16
7			Produce Final Drawings	14 days	Sat 10/09/16	Fri 23/09/16
8			Produce Final Report	14 days	Sat 24/09/16	Fri 7/10/16

Project: Second Half of the proj
Date: Sun 22/05/16

Figure 10: Gant chart detailing the second half of the project

Appendix G – Conceptual Design Models

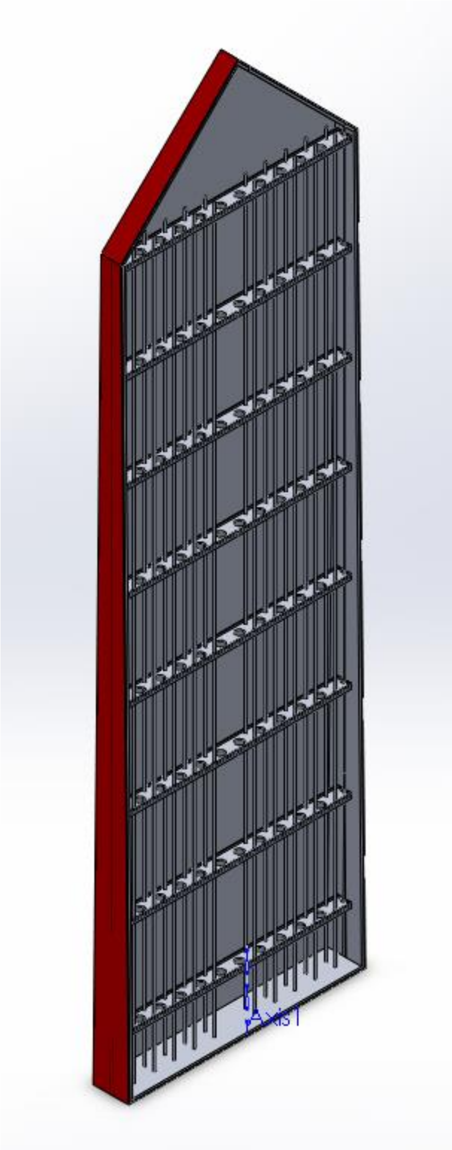


Figure 11: Initial frame design utilising an aluminium airplane wing design

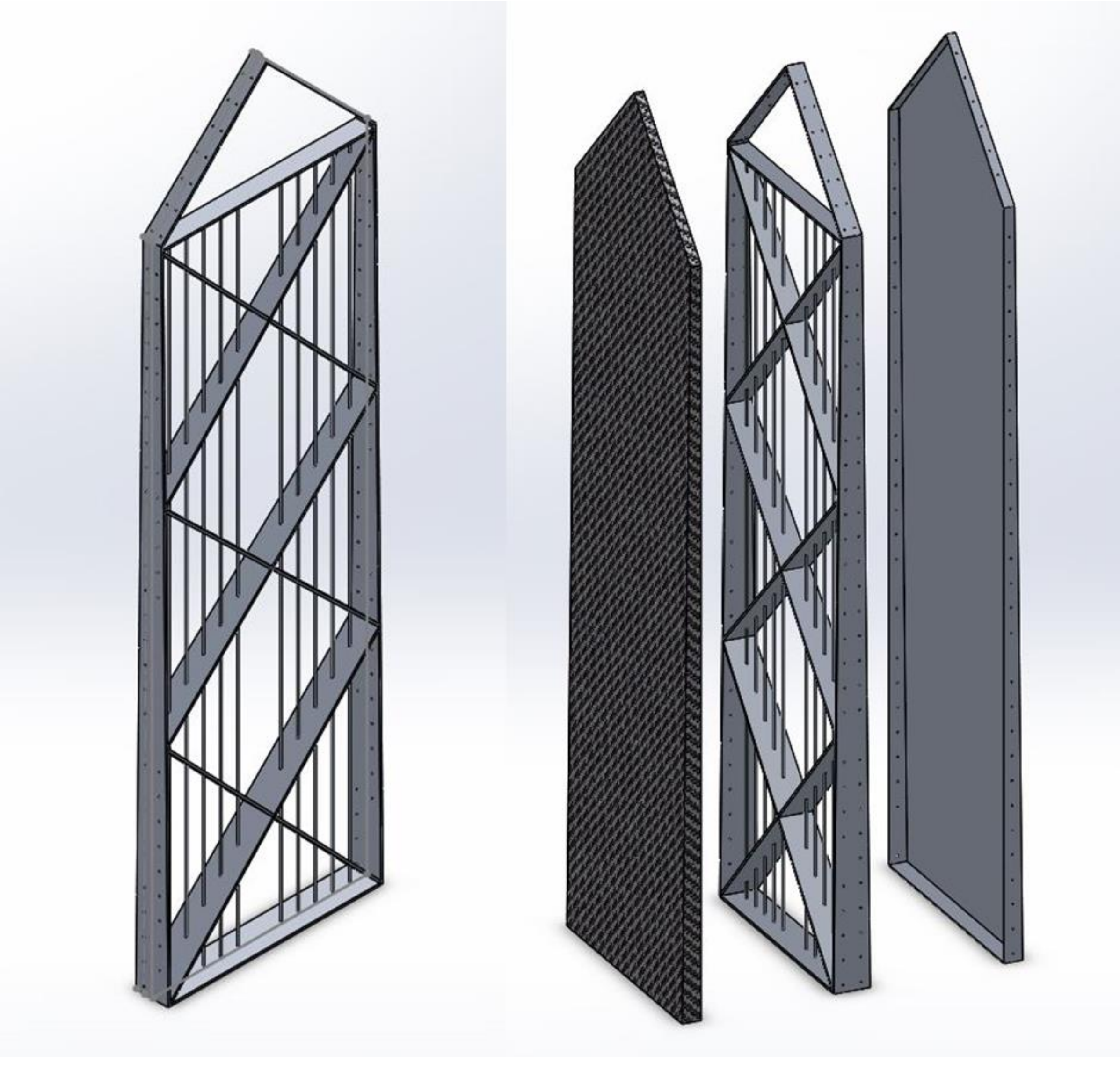


Figure 12: The second frame design, which utilises aluminium and a carbon fibre shell

Appendix H – Costs

Costs to date

Item	Cost	Notes
Skateboard bearings	$20.95	Used for 2nd Prototype
Wooden framing	$20.34	Used for 2nd Prototype
Total:	**$41.29**	

Changes to Budget

Money saved	**Cost ($)**	**Reason**
Skate board Bearings	-29.05	Money skateboard bearings for prototype were $29 cheaper than originally planned. This was due to only requiring 8 instead of 10
Aluminium sheet	-125.00	Through research and conversations with B.Robertson, it was been decided that carbon fibre would be the best material to use in the build of the final prototype. Due to this, half of the aluminium sheet budget has been re-allocated to the carbon fibre budget
3D Printing	-1,000.00	It has been decided that 3D printing is surplus to requirements in the process of making the final prototype
Total ($):	-1,154.05	

New additions	**Cost ($)**	**Reason**
Wooden frame	20.34	Wood was utilised to build the frame for the 2nd prototype instead of aluminium
Bearings for final prototype	200.00	The cost of bearings for final prototype was overlooked in the past submission
Total ($):	220.34	

Money saved ($):	933.71	
Money re-assigned ($):	933.71	This money will be re-assigned to cover the costs of the increased use of carbon fibre
Changes in total budge($):	0.00	

Updated Costs

Item	Amount	Cost/unit	Cost ($)	Notes
Materials				
Raw materials				
Polystyrene foam	2 m^2	-	0.00	Recycled
Duct tape	2 rolls	-	0.00	Provided by workshop
8mm Rod	1.5m	-	0.00	Recycled from workshop
Skateboard bearings (8 Pack)	1	$20.95	20.95	Used in prototype 2
Aluminium Sheet	2.5 m^2	$50/m^2	125.00	
Weights - lead	20 kg	$5/kg	100.00	
Wood - Frame for prototype	3.6m	$6.78/m	20.34	This has been added as a cheaper substitute from aluminium for early prototypes.
Rod (threaded/unthreaded)	2 m	$5/m	10.00	
Steel - base	2 m^2	$20/m^2	40.00	
Spring steel	2 m	$20/m	40.00	
Carbon fibre	10 m^2	$100/m^2	1000.00	Money has been moved from 3d printing to carbon fibre budget.
Bearings for final prototype			200.00	
Core - nomex or foam	5 m^2	$50/m^2	250.00	
Consumables				
Epoxy resin and hardener (for composite construction)	~16 Kg	$40/kg	633.71	
Gloves	$15	100 pcs	15.00	
Safety glasses		5 pairs	0.00	Provided by workshop
Other				
Postage costs	0.125m^3 parcel, less than 20 kgs, 5 parcels	$66/parcel	330.00	Auckland to Christchurch via NZ post
		TOTAL:	2785.00	
Machining/Fabrication				
CNC machining	5 m^2		0.00	Completed at Uni Workshop
3D printing - ABS plastic	0	$1/cm^3	$0	No longer needed
Autoclaving of carbon composites			0.00	Completed at Uni Composites Workshop
		TOTAL:	0.00	
Testing equipment				
Wind tunnel			0.00	Completed at Uni wind tunnel at Lincoln University
Travel				
University fleet vehicle (<1800cc)	200 km	$0.40/km	80.00	
Software licenses				
SolidWorks			0.00	University license
ANSYS - structural, CFD and thermal analysis			0.00	University license
PTC Creo			0.00	University license
Engineering wind loading standards				
AS-NZS 1170-2: Wind actions, structural design			0.00	University access license
TOTAL			2865.00	
Contingency	20% of overall total		573.00	
	GRAND TOTAL		**3438.00**	

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