Renovating deteriorated sand bunkers at Federal Golf Club with a focus on Self-Sustainability

Individual Portfolio
ENGN2225

Abstract

An alternative bunker system, termed the 'Airdrain' design has been developed via a systems engineering approach. The design is an improvement to the existing bunker system at Federal Golf Club and it was found that the 'Airdrain' system proved to be more *Self-Sustaining, Consistent,* and an *Aesthetic* when compared to other designs. The integrated design incorporates an effective drainage system and a revetted stacked sod exterior design. Future development and testing on the system will need to be conducted before implementing this design.

5-13-2016
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Background

The main objective in the game of golf is to get the ball from the tee off area to the hole in the least amount of shots or in the regulated shots allocated for the particular hole. A golfer will interact with a golf course by any means necessary to optimise their outcome; this results in a large amount of damage to the environment and course features. The fairways become damaged and impaired with divots, bunkers lose their structural integrity and greens are damaged consistently with high lofted golf balls penetrating the soft fragile surfaces. Consequently, regular maintenance is required to keep a course intact. The Federal Golf Club located upon Red Hill occupies 85 hectares of land, with the course running 6500 metres in length (MiClub, 2016). Maintaining and nurturing the course, and its surrounding environment has proved a difficult task for the greenkeepers.

Allan Stewart the president of Federal Golf Club explains his intentions of course management in a report. Allan wishes to develop a course infrastructure that is self-sufficient for course irrigation and maintain a high standard golf facility that is enjoyable and challenging to golfers of all levels. (Stewart, A. 2016).

The current status of greenside and fairway bunkers at Federal Golf Club is inadequate and inconsistent. Consequently, maintenance and regular repairs are necessary. In order to maintain a world class golf course, a *Self-Sustainable* solution for the sand bunkers is imperative.

Design Solution

The current bunker system in place includes a fabric matting, with a sand overfill. Without the proper implementation of drainage, sand and a defined structure, the quality of the bunker will gradually decrease. Notice in Figure 1, the sand in the bunker on the 15th hole at Federal Golf Club has gradually turned into dry hard clay. Figure 2 displays sand washing off the face of a bunker as a result of heavy rain. These figures display the effects of poorly designed bunkers and the effects they can have on golfers.

Figure 1, Bunker on the 15th hole

Figure 2, Results of a poorly constructed bunker (Vavrek, R, 2004)

The proposed solution is a sand bunker design that incorporates, a new exterior design to eliminate sand washing off the face of the bunker (Figure 2), and a drainage system to improve the consistency of the bunkers. The new exterior design is a revetted stacked sod design, which ensures bunker stability, minimises erosion and aesthetically improves the course (Figure 3). The selected drainage system was designed by '*Airfield Systems,'* called *'AirDrain.'* The system is a highly porous plastic grid located beneath the bunkers surface. It allows for the rapid lateral movement of excess water to drainage pipes (McInnes, K. and Thomas, J, 2011). The solution was developed with a direct focus on improving self-sustainability, consistency and the overall performance and satisfaction of golf members. Further justifications of these systems are detailed throughout the report.

Figure 3, Bunkers with revetted sod design. Left Photo: (Schulz, P, 2012), Right Photo: (Tampa Bay Times, 2016)

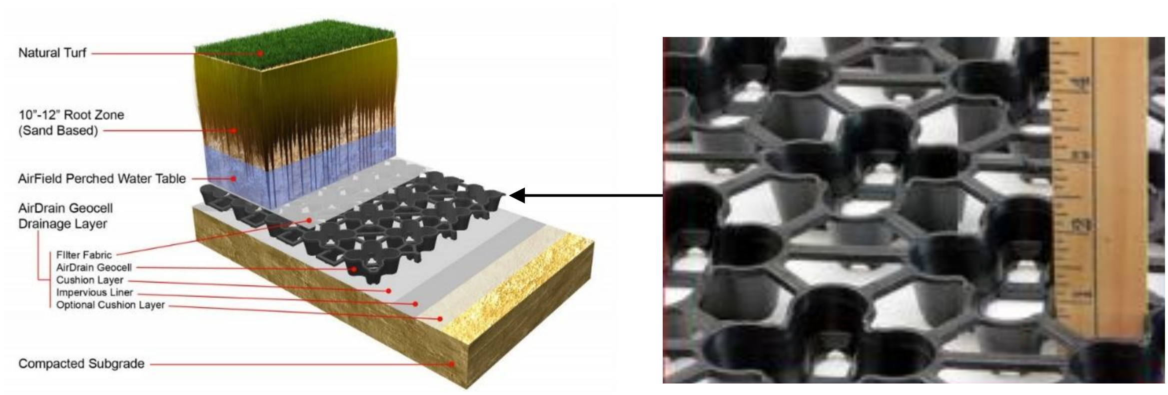

Figure 4, Cad Model of Airfield drainage system (Left), Drainage Layer (Right), (Airfield Systems, 2016).

Problem Scoping

Journey Mapping

The game of golf is one of unpredictability and when representing a journey map of a golfer playing a hole, a number of possible outcomes may occur. A journey map characterizes a user's interactions with a product, and helps to identify a customer's experience. The map will help define targets and areas of improvement within the system (Tincher, J, 2013). The journey map in figure 4 describes a simplified outcome of one golfer, playing the 10th hole at Federal Golf Club. For a more detailed analysis of how a member interacts with the current bunker system a logical flow block diagram is contained in Appendix 1.

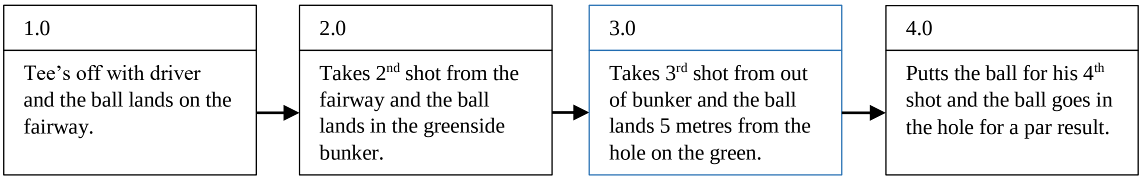

Figure 5, Broad journey map from the point of view of a golfer.

A considerable amount of shots are hit out of bunkers every day, causing an inevitable amount of wear and tear that not only effects the bunkers and the environment, but also the stakeholders involved. This project attempts to benefit major stakeholders such as the members and greenkeepers (maintenance crew).

The journey map for a member who plays at the start of the day will be similar on a broad level to someone who plays at the end of the day. However, step 3 from Figure 4 states that there are a number of uncertainties that will affect a member playing at the end of the day. These include, earlier golfers leaving the sand uneven and unraked, weather conditions creating puddles, and sand in many areas of the bunker may no longer be compact. All these problems have the potential to affect a golfers shot, thus disadvantaging him/her from the previous users. To avoid this problem as much as possible the greenkeepers have to tend to the bunkers consistently throughout the day, ensuring they are suitable for play. The labour hours and cost of maintenance to the course is currently the largest factor in the club's budget (Thompson, R. Coddington, G, 2015). A self-sustaining design will not only reduce the probability of puddles but will also reduce the amount of necessary maintenance.

The journey map in Figure 4 and the subsequent analysis provides sound insight into the effect of poor bunker maintenance on a golfer. The journey map can be extended into a detailed journey map of the refurbishment and renovation of a new bunker design, whilst integrating a stakeholder mud map.

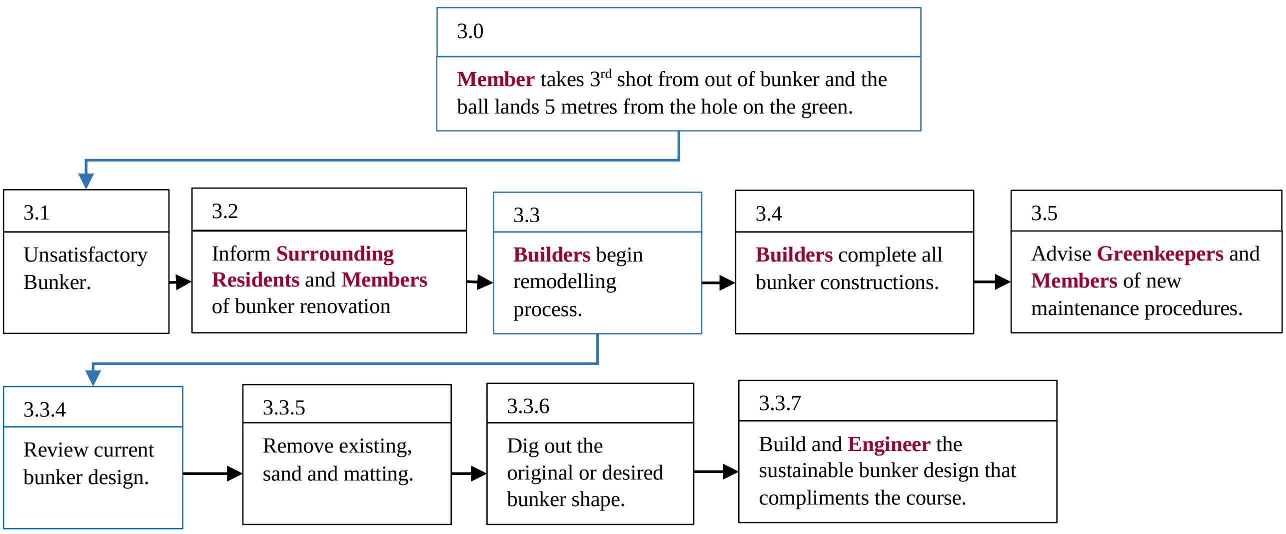

Figure 6, Journey map detailing the reconstruction procedures and some stakeholders involved.

With the stakeholders in mind, parts 3.2 and 3.5 of the journey map are essential. A policy report and course management report should be constructed and made available to all stakeholders, informing the members, surrounding residents, greenkeepers and construction crew of the new course layout and maintenance procedures.

Requirements Analysis

Customer Requirements Analysis

To deem the design successful and justifiable, it must meet the customer requirements. An analysis was conducted to ensure the final solution was beneficial to a range of stakeholders. The majority of the customer requirements were developed from Allan Stewarts report, background research, and through the inspection of the journey maps. They include *Aesthetics, Consistency, Low Cost, Fast Building Time, Low Maintenance, Escape Difficulty* and *Self-Sustaining*. In order to differentiate between most important and least important customer requirements, they were directly assessed against the stakeholders affected by them. It is important to note that throughout the report and in the following analysis, the members and greenkeepers were considered the more influential and commanding stakeholders, and thus the requirements that were long-term effect and a direct influence on the members and greenkeepers were ranked at a higher priority.

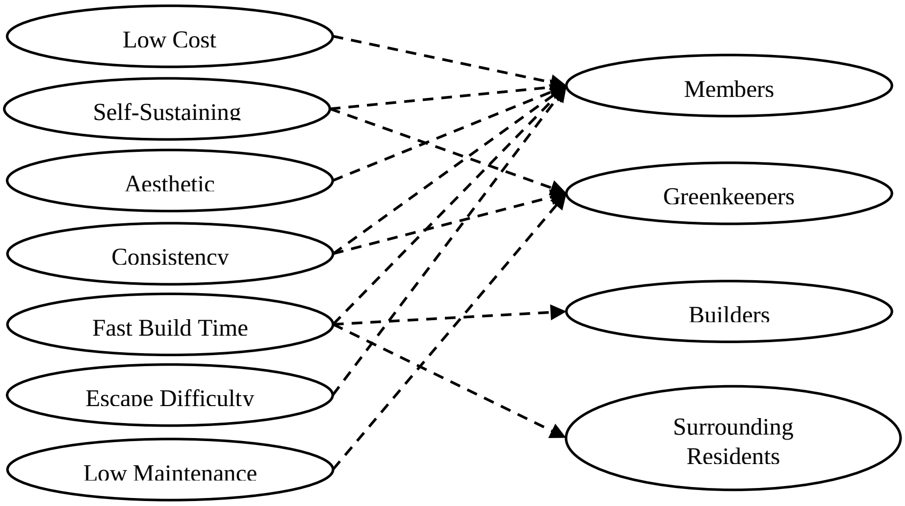

Figure 7, Tracing customer requirements to stakeholder.

Maintaining quality at a lower cost has been of paramount importance for many golf facilities over the last 5 years as they have suffered from the difficult economic conditions (Chris Hatwiger, 2013). Buying cheaper fertilizer and using generic pest controls are good short-term approaches that are worth consideration, however the main cost factor in every golf club budget is labour (Jim Moore, 2009). With this in mind developing a long term, high cost solution that is reliable and self-sustaining would be the best option to reduce the long-term labour costs. For this reason, *Low Cost* was ranked as the 6th customer requirement. It was assumed throughout the requirements analysis that the members would demonstrate more concern with the requirements that would improve their golf game. This primarily included the condition of the bunkers and their appearance, rather than the cost or the building time. Resulting in *Self-Sustainability*, *Consistency*, *Aesthetics* and difficulty ranking 1st, 2nd, 3rd and 5th respectively.

Additionally, *Low Maintenance* was ranked 4th but was of great importance. It has a low ranking because *Low Maintenance* is somewhat dependent on *Self-Sustainability*, thus if *Self-Sustainability* is achieved, then *Low Maintenance* will be satisfied. *Building Time* was ranked 7th and the lowest requirement as it is a short term requirement that primarily affected the short term stakeholder of *Builders*.

Technical Performance Measures

The customer requirements were then converted into their respected design requirements, this provided a more measurable benchmark for the system. The design requirements are considered to be ranked of equal importance with their distinguished customer requirement. In other words, the design requirements for sustainability are ranked most important were the design requirements for building time are ranked least important. Furthermore, the design requirements were defined by Technical Performance Measures (TPM's) to effectively provide a quantitative evaluation or a direction of improvement. (Blanchard, B.S., W.J. Fabrycky, 2011).

Table 2 highlighted the relationships between each of the customer requirements and design attributes. Where applicable the performance metrics for this project were sourced from the *Professional Golfers Association Tour* course conditioning guidelines (PGA Tour, 2016). These guidelines are characteristics of world-class golf courses and are the standard guidelines that golf courses both should abide by and intend to obtain.

From the TPM's table a number of interrelationships have been identified. Most notably *Sustainability*, *Consistency* and *Aesthetics* are the primary sources of influence and positive performance of the system. The design requirements of these three customer requirements inadvertently affect the success and performance of other customer requirements. For this reason; these three customer requirements will be assessed on a more detailed level throughout the report.

Table 1, Technical performance measures.

Customer Requirements	***Design Requirements***	***Units***	***Direction or Limit***	***Reference***
Aesthetics	Dimensions of the bunker must fit nicely into the course layout	Surface Area (m^2)	30-150m^2	Appendix 2.
	Depth of sand used on face	Depth (mm)	≤50mm	(PGA Tour, 2016).
	Depth of sand used on bunker floor	Depth (mm)	100-150mm	(PGA Tour, 2016).
Consistency	Density of Sand	Kg/m^3	1400Kg/m^3	(PGA Tour, 2016).
	Diameter of Sand Grain	Diameter (mm)	1mm-0.25mm	(PGA Tour, 2016).
	Depth of sand on floor and face must be consistent and within range	Deviation (%)	Decrease	No Reference.
	Minimal Silt and Clay present	Percentage (%)	≤3%	(PGA Tour, 2016).
	Relatively consistent throughout all seasons	User Satisfaction (%)	Increase	No Reference
Low Cost	Additional costs to membership fee	Dollars ($)	Decrease	No Reference
	Low upfront cost of design	Dollars ($)	Decrease	No Reference
	Low Maintenance Costs	Dollars ($)	Decrease	No reference
Fast Building Time	Time taken to renovate one bunker	Time (hrs)	Decrease	No Reference
Low Maintenance	Time it takes to rake the bunker after use	Time (minutes)	Decrease	No Reference

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	How long it takes to repair bunkers	Integer/ Time (minutes)	Decrease	No Reference
Difficulty	Height of the bunker face	Metres (m)	0.50-6m	Appendix 2.
	Distance away from hole	Metres (m)	1m-180m	Appendix 2.
	Angle of bunker face	Degrees (°)	170°-120°	Appendix 2.
Self-Sustainability	Lifespan of the bunker	Years	<10 years	(Jacobson, R, 2015)
	How often maintenance is required	Integer	Decrease	No reference
	Water is effectively drained into dams for re-use and storage	Rate (mm/hour)	500mm water per hr	(PGA Tour, 2016)

Idea Generation

The problem scoping analysis identified the problem, and provided the all-important question of, 'How might we improve the current condition of the bunkers at Federal Golf Club'? From this question a number of concepts were generated. The concepts were either modifications to the current system or complete renovations, whilst keeping in mind the scope of the system and the customer and design requirements. It is evident that some solutions satisfy particular design requirements more than others. This is displayed in a solution, were replacing the bunkers with fairway grass represents a simple and cheap solution, however it is out of the scope and does not provide an improvement on bunkers. In contrast, a revetted stacked sod design is potentially cost effective, economical and will dramatically improve the overall aesthetics of the course.

Concept Classification Tree

The solutions were divided into four solution categories; these included subterranean, maintenance, protection, and rebuilding the bunker. These systems are branches of individual solutions, however can be integrated together to provide an optimized design.

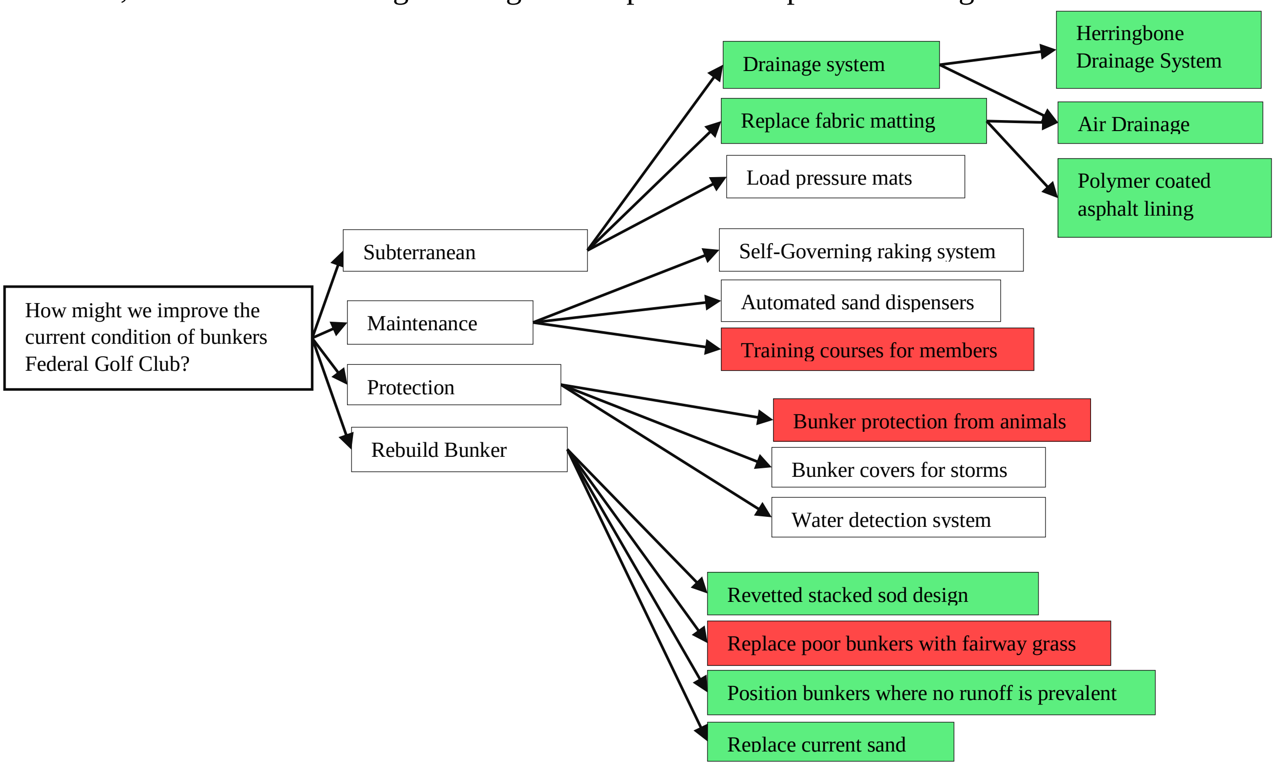


Figure 8, Concept Classification Tree

A number of concepts generated were filled with a red background to indicate the concept is not within the scope of the system and does not fulfil the principle customer and design requirements. In contrast the concepts that are filled green were selected for further evaluation, and assessed for a combined interconnecting solution. A pruning process was conducted to identify and differentiate the promising solutions from solutions that appear to have little merit. (Ulrich, K.T., Eppinger, S.D, 1995). Solutions developed from maintenance and protection systems were not considered for further evaluation. A self-governing raking system, automated sand dispensers and water detection systems appeared to have no practical application, and would significantly increase the cost, and building time of the system. When researching these solutions there was a limited amount of scholarly resources and information, for implementation and development of the designs. Therefore, it was concluded that these solutions would result in unfinished and unreliable design. Some of the solutions developed from the 'Subterranean Systems' and 'Rebuild' categories were acknowledged. Desktop research on drainage solutions revealed a number of designs that already exist and have been adopted by world class golf courses around the world. Particularly, the '*AirDrain'* and '*Herringbone Drainage'* systems, which both provide uniform drainage at every part of the bunker, and consequently satisfy the customer requirements of *Self-Sustainability, Aesthetic*, and *Consistency*. The revetted stacked sod design has also proved to be a reliable solution, it not only increases the *Aesthetics* of the bunker, but also eliminates sand run-off, and increases the lifespan of the bunker faces (Turner Macpherson Golf Design 2007), this consequently improved the *Consistency*, and *Sustainability*.

Functional Analysis of Solutions

Integrated Solutions

Generating a functional flow block diagram (FFBD) of solutions selected in the concept classification tree will help to outline the benefits that the solutions have. Rather than evaluating a single idea, multifunctional interconnecting systems will be assessed which will incorporate multiple solutions from the concept generation tree. The integrated solutions include two bunkers designs, which will be referred to throughout the rest of the report as a USGA Design and an Airdrain Design. They include:

USGA Design

- A herringbone drainage system with perforated pipes, superimposed with a matrix liner (Matrix Bunker System, 2016) or superimposed with a 50mm layer of gravel with a ST410 polymer coating (Lowe, T, Vavrek, B, 2015). Additionally, a revetted stacked sod exterior design (Figure 2), accompanied with tested and suitable sand.

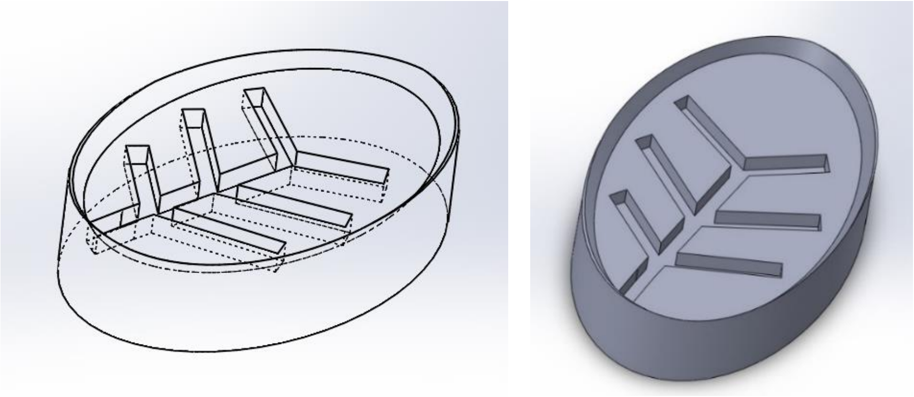


Figure 9, Herringbone Drainage System

Figure 10, Polymer matrix liner superimposed over the herringbone drainage system. (Matrixbunker, 2016).

Airdrain Design

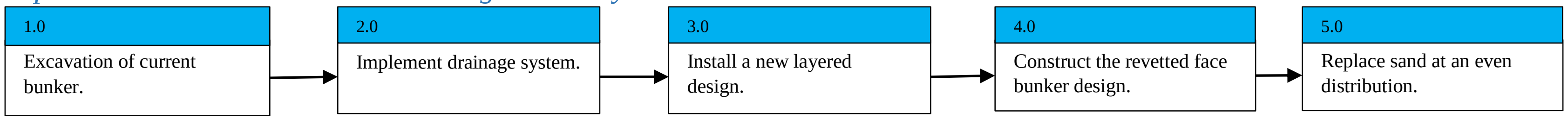
- The *'Airdrain'* includes a single perforated pipe located below the *'Airdrain'* system connecting to the dam drainage lines. It will be superimposed with the inclusive geotextile liner and filter fabric. Additionally, a revetted stacked sod exterior design, accompanied with tested and suitable sand. (See Figures 3 and 4)

In Figure 8 there is a second level detailed Functional Flow Block Diagram (FFBD), demonstrating the construction and renovation of the new bunker system. This FFBD is a detailed extension of the integrated journey map in Figure 5. The FFBD will give perspective on how long the construction phase may take. *Fast Building Time* was ranked 7th in the customer requirement analysis, however it is important to keep the influence in mind.

The allocation of these functions is conducted via a top-down approach, with broader top-level functions being defined initially, before successive lower-level sub functions are generated (Blanchard, B.S, Fabrycky, W.J., 2011). Stage one in the FFBD is a significant stage in the development process, excavating the new profile and shape of the bunker will influence the overall structural integrity and will directly affect the other 4 stages. The installation of a subterranean system at stage 2 and 3, will ensure *Self-Sustainability* of the bunker, and will play an essential role in maintenance and performance. During the harsh wet winter seasons, contamination of the bunkers will be reduced, and ponds of water forming will be eliminated, providing desirable and consistent bunkers.

Functional Flow Block Diagram

Top Level Functional Flow- constructing the new system



Second Level Functional Flow-constructing the new system

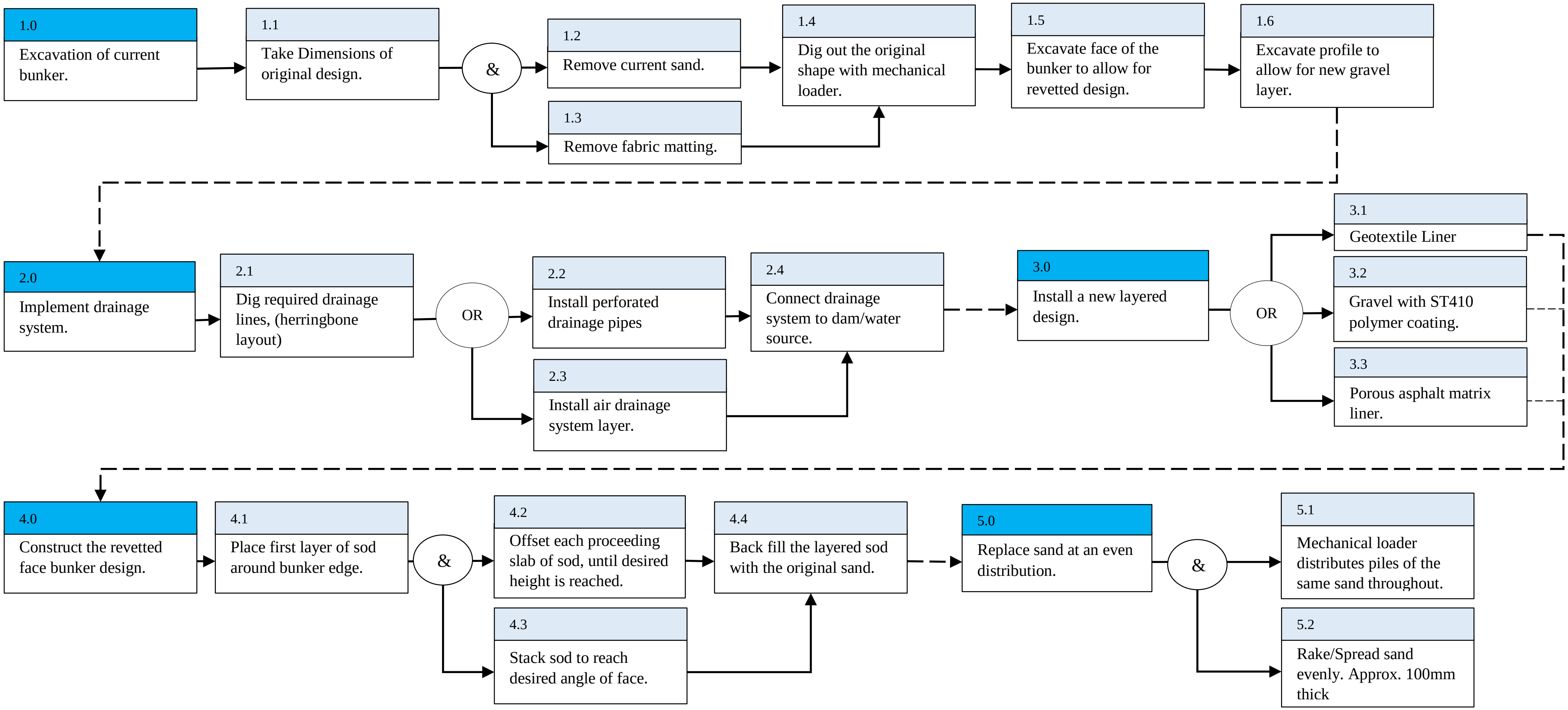


Figure 11, Functional Flow chart analysing the construction process of the system.

Preliminary Testing on Drainage Systems

In the functional flow block diagram there are a number of 'OR' functions that denote the different options of the USGA design and the *'Airdrain'* design. At this stage of the systems engineering process, analytical testing will be conducted to converge on one particular solution.

An advantage of using a commercial off the shelf drainage system means that a progressive testing and an evaluation process has already been conducted on the product. The United States Golf Association conducted a number of preliminary system design tests for the drainage system. These types of tests revolve around the testing of individual components of the system to ensure functionality. (Blanchard, B.S, Fabrycky, W.J., 2011). The tests compared the '*Airfield'* drainage system to a herringbone drainage system and from the results; there was a noticed increase in water storage of about 0.5inches (McInnes, K. and Thomas, J, 2011). As a result, the likelihood of the bunkers becoming flooded decreased, whilst also increasing water retention for repurposing later on. With an increase in water retention the system is in absolute agreement with the *Self-Sustaining* customer requirement and Allan Stewarts course management goals. An increase in water retention will also consequently lead to a less frequent necessity to irrigate. The preliminary tests were conducted using a number of PVC pips were different types of sand, different geotextile liners and different drainage systems (Figure 9). The testing procedures conducted here are not only objective by are also repeatable. The tests are relatively simple to construct and are tested over a period of 24 hours. For this reason, a similar testing procedure should also be conducted using the sand available at Federal Golf Club to ensure functionality of the system within the context of Federal Golf Club.

Although a herringbone drainage system is the most common bunker drainage method, the likelihood of the drains becoming clogged or collapsed overtime is inevitable. (Lowe, T., VavRek, B, 2015) The geotextile liner that had an opening size of 0.2mm effectively retained the sand and prevented the migration and passage of the sand into the drainage layer. (McInnes, K. and Thomas, J, 2011) Thus minimising the chance of clogging, reducing the necessary maintenance of the drainage system and overall increasing the lifespan of the bunker system, which are both design requirements associated with *Self-Sustainability*.

Figure 12, Testing conducted using different sand and drainage techniques. McInnes, K. and Thomas, J. (2013).

System Architecture

System Interface Map

Defining the boundary of the bunker design, the discrete subsystems involved, and the respected components in each subsystem, will assist in demonstrating how the subsystems interact within the bunker design. Before the functional flow block diagram is created it is important to define the system boundaries and establish what is inside and outside of the scope. A system boundary chart is displayed in table 2, the internal column defines what can be controlled, the external column defines the influences that affect the system but are cannot be controlled, and the excluded column are the factors that will not be taken into account at this stage of the systems process (Herrmann, D.S, 2001).

Table 2, System Boundary Chart

Internal	***External***	***Excluded***
Bunkers	Maintenance	Animals
Dimensions	Member (Golfers)	Water Dam
Drainage	Surrounding Residents	Irrigation
Exterior Design	Environment	Weather (seasons)
Sand	Builders	Surrounding drainage pipes
Cost		

The functional flow block diagram has provided 5 distinct subsystems and their inputs and outputs, including excavation, drainage, lining, revetted design and the sand. The majority of inputs and outputs of the system have been derived from the TPM's (Table 1) and the system boundaries have been adopted from the systems boundary chart.

For this design the *'Airfield'* drainage system will be analysed as it proved the superior through analytical testing. Note that the *'Airfield'* drainage system is commercial off the shelf product that is inclusive of a geotextile lining subsystem (AirField Systems 2014). For the purpose of the FBD diagram the two subsystems will be classified under one "Subterranean System." The FBD is used to determine which subsystems influence and relate to the customer and design requirements, this is important for traceability, so it is obvious which design requirements will be affected if there are modifications to a subsystem.

The functional block diagram exhibits the system and subsystem interactions for the proposed Airdrain bunker system. The flow of input and output between the subsystems indicates the dependent and independent nature of the overall bunker system. From inspection it is noticed that the excavation subsystem will always have an effect on the subterranean system and its subsystems, which will consequently affect the exterior system. For the FBD in Figure 1, the drainage system implemented was a commercial off the shelf system (COTS) which is a design that is inclusive of both the drainage subsystem and the lining subsystem. Due to the implementation of this commercial off the shelf system, modularity of the system decreases, however reliability and robustness increases.

Functional Block Diagram

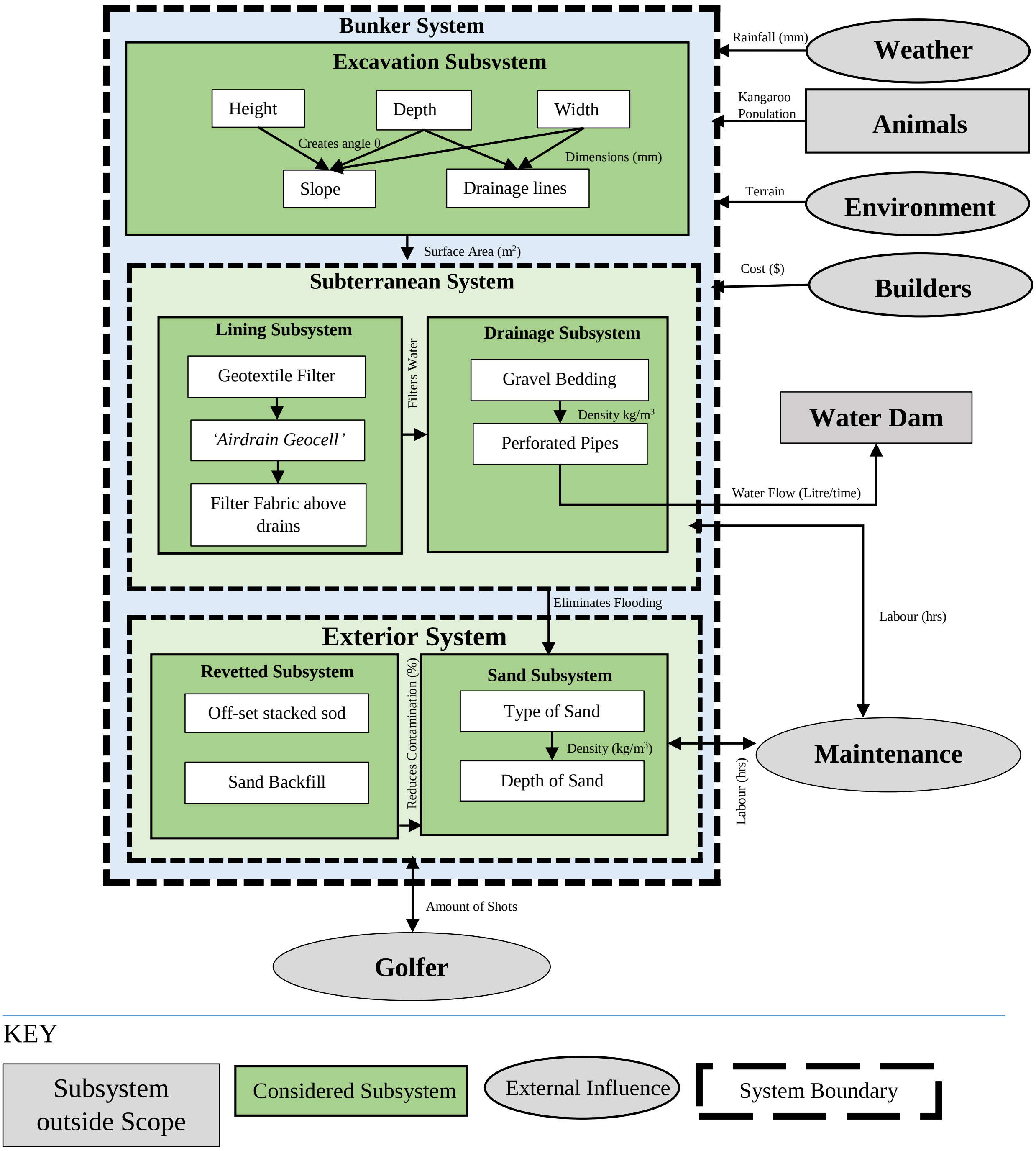


Figure 13, Functional Block Diagram

A principle design requirement that was outlined in the technical performance measures was consistency in the density of the sand. The inputs from the lining subsystem, drainage subsystem and revetted subsystem all influence the consistency of the bunker. Through elimination of puddles, reduction in sand contamination and a consistent drainage system, that will allow all of the bunkers around the golf course to filter water at the same rate.

Tests for Future Validation

The tests conducted on the drainage systems may be reliable, however they are directed at only two customer requirement. The reliability of this system is based on the overall customer requirements of the bunker, and thus the system must undergo a number of other rigorous tests. With the information gathered from the system architecture, a basis has been provided on how the system will interact with respect to each discrete subsystem.

Using the FBD is a good tool that illustrates the relationships between the systems, however a more quantitative evaluation of the system is required to ensure the system meets the customer requirements. An attributes cascade table directly relates the design requirements to the attributed subsystems, components and the affected stakeholders. The customer requirement of *Self-Sustaining* and *Consistency* will be analysed, note that these were ranked 1st and 2nd in the customer requirements.

Table 3, Cascaded Attributes Table

Customer Requirements	**Design/ Functional Requirement**	**Related Subsystems**	**Component**	**Stakeholder Effected**
Self-Sustainability	A1 Increase Lifespan of the bunker	DS, LS, RS, SS, BTS	All	Greenkeepers, Members
	A2 Reduce maintenance required	DS, LS, RS, SS, BTS	All	Greenkeepers
	A3 Water is effectively drained into dams for re-use and storage	DS, LS, SS	All subterranean components, type of sand.	Greenkeepers, Members
Consistency	B1 Density of Sand	SS	Type of sand, Depth of sand	Members, Greenkeepers
	B2 Diameter of Sand Grain	SS	Type of Sand	Members, Greenkeepers
	B3 Depth of sand on floor and face must be consistent and within range	SS	Depth of Sand	Greenkeepers, Members
	B4 Minimal Silt and Clay present	RS, SS, DS, LS, BTS	All	Greenkeepers, Members
	B5 Relatively consistent throughout all seasons	DS, SS, RS, LS, BTS	All	Greenkeepers, Members

Subsystem Key: DS=Drainage System, LS=Lining System, RS=Revetted System, SS=Sand System, Excavation System, BTS=Beyond the Scope.

It is clear from the cascaded attributes table that the modularity of this system is poor. Four out of the eight design requirements are influenced by all of the subsystems, inclusive of systems beyond the scope of the project. This means that if one of these subsystems change then four design requirements will have to be re-assessed for functionality. It was also noticed that the sand subsystem had an effect on all design requirements, thus if the components attributed to the sand subsystem changed then the greenkeepers and the members were always effected.

Testing for the bunker design should ensure that the design requirements in table 3are all met and the functionality of the related subsystems and components are apparent. Further testing on some of these design attributes are outlined below.

Table 4, Testing Procedures Outlined

Attribute to Test	Type of Test	Testing procedure	Pass Criteria
A1 Increases Lifespan	System Prototype	Setting up a prototype test bunker on the practice greens	Meets TPM of greater than 10 years.
A2 Reduces Maintenance Required	Operational Testing	Using prototype bunker, collect data from greenkeepers, determine the mean for active, corrective and preventative maintenance time.	The labour (hrs) and cost of maintenance is decreased when compared to current system.
B2 Diameter of Sand Gran	Proof of Concept	A penetrometer reading obtained from a USGA accredited lab as well as particle size distribution and water infiltration rate.	65% of sand should be between 1mm and 0.25mm. Nor more than 25% should be 0.25mm or smaller. No more than 5% of total sand should be .15mm or smaller.

Future Developments

The system is still far off from implementation, and before construction begins the stakeholders must be convinced that the system will be beneficial and reliable. The current state of the system is just an idea, but for the stakeholder to be satisfied the idea needs to become tangible and realistic. For this to occur, a prototype bunker should be implemented onto the practice greens, to allow testing for functionality, and the overall performance and effect that the design has on the golfer's game, whether positive or negative. Before the prototype can be established, thorough testing must be conducted in the context of Canberra's climate and environment.

A development that needs to be investigated further is the option for a more modular system, this would ensure that the bunker system remains functional if a subsystem was to fail. Currently the subsystems are all dependent on one another and thus if one thing goes wrong it will affect the greenkeepers, members and the majority of customer requirements. A back up plan should be revised in case a component in the system fails.

Although the researched data for the *'Airfield Drainage'* may be reliable and effective for other places around the world, it is still unclear whether it will be as effective in Canberra. To compensate for this lack of data the climate experienced at Greens Country Club (golf course that has adopted '*Airfield System*') was researched and compared to Canberra Climate. At Greens Country Club in Oklahoma City the average annual rainfall was recorded at approximately 880mm, with an average yearly temperature of 16 degrees. (US Climate Data, 2016). In comparison the annual rainfall in Canberra is recorded at 636mm, and the average yearly temperature was recorded at 14 degrees (Bom.gov.au, 2016). Thus indicating that the system would be a reliable solution for Canberra's Federal Golf Course.

Reflection

When developing an idea for my portfolio, I found that the it was a lot easier deconstructing a problem that I encountered regularly. Not only did I have a basic conceptual understanding of the problem but also I knew what the problem was and what research would have to be conducted to find a solution to this problem. I found that I learnt best in this course by making the most of the seminars, online classrooms, core resources and reading the design toolkit. In each these particular methods of teaching, the systems engineering techniques were applied and used in a number of different ways which helped me to understand how, and were I could integrate these techniques into my portfolio.

Some rather informal methods of teaching that I adopted throughout the course, was developing my ideas with my peers, Chris and Nicole. I found that all feedback was good, whether positive or negative, and it helped to remove unnecessary parts of the portfolio and also extend important parts of the portfolio. In particular, Chris gave me some good advice on integrating the stakeholders into the requirements analysis to improve traceability.

I treated the TC's as the initial loop around the systems spiral design process. However, I found it necessary to do the majority of research and development of the design during the TC iteration. When collating my TC's the page count was approximately 25, the reason I spent so much time on my TC's was so I could gain as much constructive feedback from Nicole as possible. Thus when it came to designing my final portfolio I could remove the sections that were criticised and integrate the techniques that were commended. The final portfolio was treated as the second loop around the spiral design and consisted of a lot of pruning of ideas and forming a portfolio that communicated the same messages throughout.

I found the peer review process helpful, and it highlighted sections in my portfolio that weren't clear or just weren't explained well enough. Not only were the reviews helpful but I found marking someone else's work helped me to develop some of my own techniques and highlighted sections that I needed to improve on. Without being subjected to these portfolios, I am almost certain that the majority of my conclusions and analyses would have been insufficient.

A common criticism that I received in my peer reviews was a lack of scholarly resources, and whilst I thought I had developed a sound reference list, it was brought to my attention that these resources were mainly websites of 'off the shelf products'. For my project it was difficult to find resources through the ANU library, however I found a golf data base 'USGA' that provided reliable resources and evidence that backed up my conclusions and arguments.

A contemporary issue that I found affected a lot of golf courses were the drainage and irrigation systems in general, for bunkers, greens, tee off areas and even the dams. If I was to do this report again I would focus on developing an irrigation and drainage system for the whole course rather than the just the bunker system itself. This would help to provide an even greater *Self-Sustaining* course.

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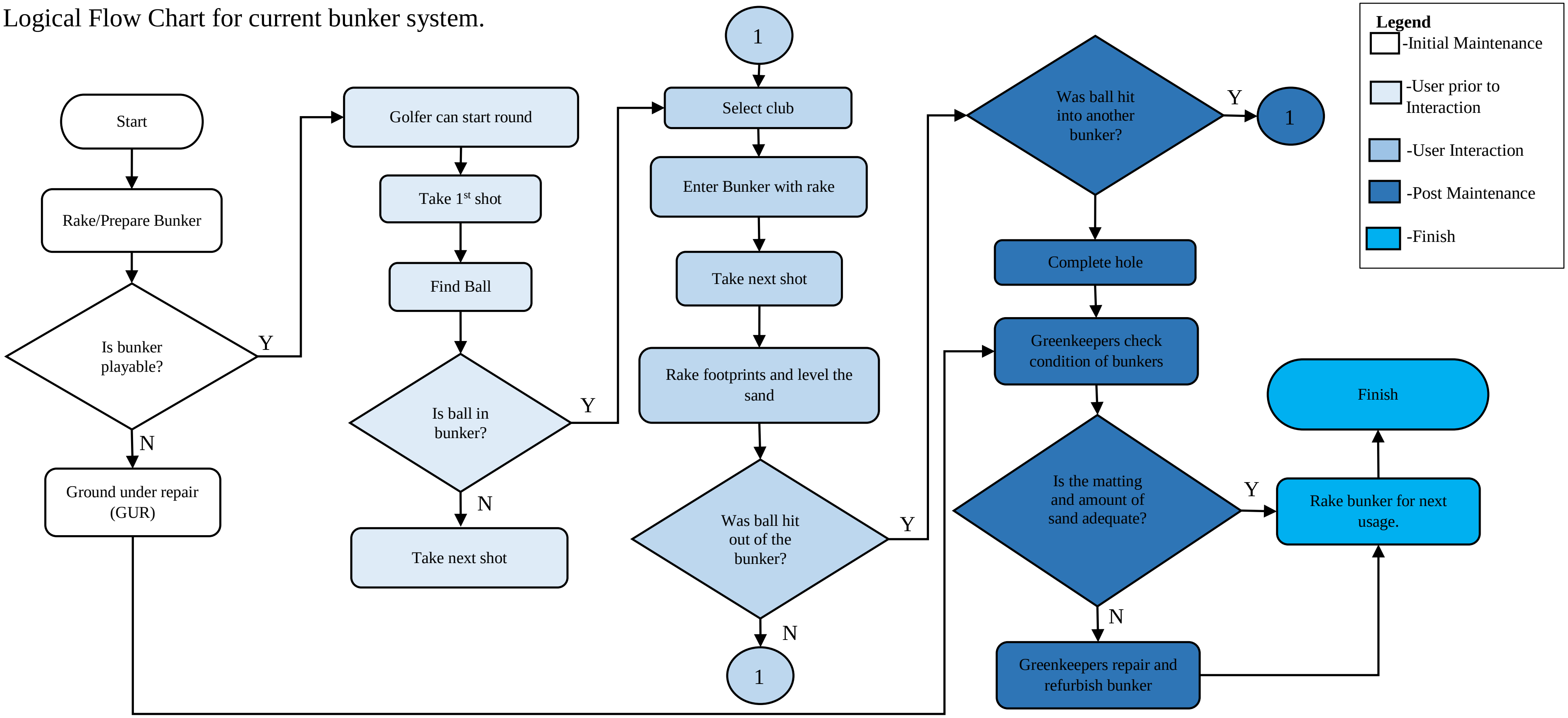
Appendix 1

Logical Flow Chart for current bunker system.



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Appendix 2

Birds eye view of course. (MiClub, 2016).