AN ENVIRONMENTAL FRIENDLY OPTIMIZER FOR LANDSCAPE DESIGN (ENVO-LAND)

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Abstract- Proper plant selection plays a vital role in landscape planning and design. It has been reported that real estate projects can save between 44%-50% in landscape annual operating costs in case of applying optimization technique in selecting their plant types. Plants consume huge amount of water over their life. However, there is a lack of supporting optimization tools that help in the selection of proper mix of plants to achieve minimum operating and replacement costs. The current selection of plant mix depends mainly on individual architectural judgment and self-experience in selecting the plant types. This paper describes the development of a an environmental optimizer for Landscape design that aims to support architects to deliver landscape designs which are aesthetically attractive while being cost effective and environment friendly. The system contains a built-in optimizer that takes architects' requirements, and matches them with the most cost effective and least water consuming options. The literature research on plants' databases, in addition to the field research with architects, suppliers and contractors, led to the most commonly used attributes to best represent the plants to be fed to the optimizer. These includes: Dimensions, Bloom Season, Life Cycle, Light, Salt Tolerance, Drought Tolerance, Irrigation/Water Demand and Cost. An interface was made which takes the input from the architect and processes it through the optimizer along with the database entries, then outputs the results in a table that is easy for the architect to utilize in his/her design. The optimizer is built using the knapsack dynamic programming model; this allows for the rapid solving of the multi-objective problem to reach a set of plants that minimize the cost, as well as the water consumption.

Keywords- Landscape, Optimization, Water Demand, Life Cycle Cost, Sustainability.

I. INTRODUCTION

The real estate industry represents a major component of the global economy. In year 2012, the real estate volume reached US$ 241 billion in the Americas, US$ 195 billion in the EMEA and US$ 127 billion in Asia Pacific (JLL, 2014). In the same year, the values in Egypt reached US$ 5 billion (GAFI, 2013).

A recent publication (Fayad, 2014) reported that the urban landscape in Egypt represents on average 3.5% of the real estate investment with an average of EGP 1.3 billion per year with a respective equivalent annual operating expenditure of almost the same amount. Moreover, the average annual irrigation water consumption for urban landscape is estimated at 820 million cubic meters.

Cost savings, preserving natural resources (especially water) and sustaining the environment are ever pressing demands of all governments, companies and conscious individuals.

II. LITERATURE REVIEW

Designing sustainable and cost effective landscape is a very challenging topic. In large scale mixed use real estate projects and gated communities, the lifecycle cost of urban landscape projects represents a major component that consumes difficult-to-track running costs. As a type of cost to be transferred to residents or end users, proper cost estimate, cost optimization and cost analysis need to be conducted to ensure a competitive edge for real estate projects in their market. It is not an easy task for urban landscape architects to select their plants types for the projects they design and consider several requirements at the same time. The shape of their landscape plants design should be rich, sustainable, and attractive over its life and consume less irrigation water. The design should also be of less capital and operating costs, i.e. less lifecycle cost.

Moreover, plant selection should be performed in a dynamic way since the lifetime of plants differ from plants' group to the other. This provides the option of selecting different plant types when it's required to replace the deteriorated plants by new ones. The periodic selection of plants is important in the sense that it supports urban landscape architects in selecting their plant types as well as meeting a number of additional requirements.

A little research has focused on minimizing the urban landscape lifecycle cost and the impact on the end users who usually finances such costs. Roberts et al (2010) introduced an Evolutionary Multi-objective Optimization methodology for generating estimates of the Pareto optimal set of designs for an evolving landscape in the rural urban fringe of a major metropolitan area. Although the method is able to provide optimum designs from ecological point of view, it has not considered the lifecycle cost optimization of the output landscape design.

Jienan (2009) discussed the landscape design for three cases in china. The study has discussed three dimensions that should be considered while designing landscape, namely:

1) Similarity in design and lack of own characteristics while designing residential landscape,

2) Lack of functions in the design of residential area, and
3) Energy consumption and lack of conservation techniques, e.g. solar and wind energy.
However the study does not consider the plantation lifecycle costs.

Brunckhorst et al (2006) described three principles for prioritizing the management of natural resources within different regions. They included that resource management within the regions should reflect the perception of local resident communities as one of their principles in addition to selecting a relatively homogeneous set of landscapes with similar climate, ecological and geophysical characteristics. However little or no literature has addressed the urban landscape design in such a way that maintains the sustainability of available resources, e.g. irrigation water or lifecycle operation and maintenance cost.

There are also a number of packages that were developed to select plant mixes. The available packages provide basic landscape databases that are usable in certain regions of certain climate/soil conditions. These packages include several parameters for different landscape plant types. The available packages enable landscape designers to select certain plants in their designs as well as drawings' capability. However, the available packages do not provide optimization capability neither from cost nor from water consumption perspectives.

Department of Horticultural Science, University of Minnesota, developed software "SULIS" for selecting Plant Elements. The goal of the software is to provide sustainable landscape information to the public and to the horticulture/landscape industry. By utilizing SULIS concepts, homeowners, business owners and related industry personnel are able to create outdoor spaces that are functional, maintainable, environmentally sound, cost effective and aesthetically pleasing (UOMinn, 2014). CAD Pro landscape design software was developed by CADPRO for quick seeing the dramatic transformation of undeveloped spaces (CADPro, 2014). In addition, SmartDraw developed a real time landscaping software that is useful for easy design, planning and drawing of urban landscape. An extensive plant encyclopedia and plenty of template assist in building home's landscape elements. There are few design tools missing, and it does not import as many file types as one would like (SmartDraw, 2014). In addition, Department of Horticulture and Crop Science, Ohio State University developed software for static selection of plant type (OSU, 2014).

On the other hand, a Proof of Concept landscape plant selection model was developed (Fayad, 2014) whose approach is based on providing plants' mix design with optimized lifecycle cost or irrigation water consumption. The model applied Artificial Intelligence AI as an optimization tool to reach an optimum solution of the objective function. Through utilizing plant database information in Egypt, the Sustainable Landscape Optimization Model, SLOM, provides plant mix design with minimum lifecycle cost, capital as well as operating cost for the selected plant types. It can also select plant types mix design with minimum irrigation water consumption.

III. OBJECTIVES

The objective of this paper is to develop an optimization framework capable of solving the architects' needs of designing an aesthetically attractive landscape that is aesthetically attractive while at the same time being cost effective and environment friendly.

IV. SURVEY OF PLANTS' DATA SOURCES

The survey was conducted through field and literature research approaches:

- The literature research was conducted through surveying existing databases with the aim to develop methods to geographically classify each plant, as well as analyzing their content and filtering through them.
- The field research was conducted through meetings with suppliers, architects and contractors.

Integrating the literature and field research, the researchers started formulating the main aspects to be considered in developing the ENVO-LAND database; the geographic plant classification, the identified plant attributes and how they could be collected from the surveyed databases and the database structure.

The team started looking into available databases in the market. The Plants Encyclopedia of Egypt (2009) published by the Red Sea Sustainable Tourism Initiative, contained a head start number of plants with basic characteristic information and cultivation environment. In addition, a planting glossary of the Al-Azhar Park in Cairo (2013) was recently published. This planting glossary is more in depth; it has an expanded array of plants categorized according to plant type (palms, trees, shrubs…etc.), and the associating plant information is more structured. It provides further design usage and character in addition to the basic plant dimensions.

There are several online and softcopy databases covering regions other than Egypt such as the US and the Gulf area which were also visited and checked. The associating plant information after several sources began to formulate common fields of plant characteristic and information. Most had common characteristic/dimension fields and minor deviations in presenting the cultivation environment. Some sources provided design usages and aesthetic information about the plant as well. The online databases had more records, however most of which were search engines and crowd sourced. Accordingly, online sources were secondary references in terms of data; however were good references in terms of the user interface and user journey.

After having conducted the survey of existing databases, the research team decided to run interviews on the field in order to complement any missing data that is practically used by professionals in the area. The interviews were conducted through personal meetings with supplier representatives, conference calls and a series of market surveys. Following are the plant attributes that were identified through the literature review and field surveys that cover the factors that the landscaping architects consider for producing their designs. Table 1 shows the depicted attributes in the surveyed databases.

Table 1 : Availability of the selected attributes in each of the databases

	DB (3)	DB (4)	DB (5)	DB (6)	DB- (7)	DB (8)	DB (9)	DB (10)	DB (11)
Classification	Y	Y	Y	Y	Y	Y	Y	Y	Y
Type	Y	Y	Y	Y	Y	Y	Y	Y	Y
Genus	Y	Y	Y	Y	Y	Y	Y	Y	Y
Species	Y	Y	Y	Y	Y	Y	Y	Y	Y
Latin Name	Y	Y	Y	Y	Y	Y	Y	Y	Y
Common Name	Y	N	Y	Y	N	Y	Y	Y	Y
Arabic Name	Y	N	N	N	N	N	N	N	N
Dimensions	Y	N	Y	Y	N	Y	Y	Y	Y
Bloom Season	Y	N	Y	Y	N	Y	N	Y	N
Design Usage	N	N	N	Y	N	Y	N	N	N
Life Cycle	N	N	N	N	N	N	N	Y	N
Light	Y	Y	Y	Y	Y	Y	Y	Y	Y
Salt Tolerance	Y	Y	Y	Y	Y	Y	Y	Y	Y
Drought Tolerance	Y	Y	Y	Y	Y	Y	Y	Y	Y
Irrigation/Water Demand	Y	N	N	N	N	Y	Y	Y	Y
Cost	N	N	N	N	N	N	N	N	N
Maintenance	N	N	N	N	N	N	N	N	N
Hardiness Zone	N	N	Y	N	Y	Y	Y	N	N
Environmental Concerns	N	N	N	Y	N	N	N	N	N
Totals	13	8	12	13	9	14	12	13	11

V. PLANT SELECTION AS AN OPTIMIZATION PROBLEM

The process of landscape design can be modeled as a design optimization problem whereby the landscape designer aims to select a limited number of plants from a large number of available species such that each plant satisfies a number of design requirements (e.g. height, bloom season, color, shading, spread, etc…) and the overall collective selection of plants minimizes one or more design objectives (e.g. Life cycle cost, total water consumption, etc…). Essentially, landscape designers will have certain requirements in terms of the types of plants they need for the project at hand. For example, a landscape designer may decide to use deciduous trees, palms and hedge shrubs in certain location of the project. The landscape designer will have in mind the location of these three types of plants but may not have settled on the exact deciduous tree, or exact palm or hedge shrubs to use. Faced with many choices for each plant type, the landscape designer may decide to look for the exact plant in a database. Furthermore, there may be different quantities required of each to meet the landscape designer's vision for the project and to satisfy the design. For example the landscape designer may be looking for 10 palm trees, 3 deciduous trees and 4 meter run of hedge shrubs. Therefore the designer is actually looking for the exact choice for each plant type, i.e. whether to use oak, maple, and hickory trees for the deciduous trees, and whether to use Alexander Palms, Areca Palm or Bismarck Palm (these are three types of palm trees) and so on for the shrubs.

Under each plant type, the landscape designer may be looking for exact choices that meet certain conditions of height, color, shading, spread, and blooming season. Some of these selection factors will be in the textual form such as blooming season or plant shape, others may be in numeric form such as space requirements for the plant, while others may be given in the form of numeric ranges such as the height. Sifting through the database (or filtering an electronic database), the landscape designer may provide filter criteria and select the choice that best meet his needs.

In addition to the above factors that affect the selection of the exact plant type, there are two very important criteria that need to be addressed. The life cycle cost of the plant including the cost of maintenance as well as initial cost is one of the most important criteria in selecting the plant. Another important criterion is the water consumption, which is very important in dry and temperate climates. These two criteria can be used as the two main criteria for selecting the exact plant types, while meeting the constraints on all the other factors or needs from the landscape designer such as the height, color, shading, spread and blooming season.

As such the problem of selecting the plants in a landscape project can be formulated as an optimization problem, where the variables for the problem would be the exact plant to select from each type. By varying the exact plant type to use, i.e. whether to use oak, maple, or hickory trees for the deciduous tree plant type and whether to use Alexander Palms, Areca Palm or Bismarck Palm for the palm trees palm type etc., the total amount of water consumption and the total cost of the project will vary. Therefore, the objective of this optimization problem is to reduce the water consumption and the cost. This is the objective of the optimization problem at hand. The goal of reducing the water consumption may conflict in some cases with the goal of reducing the cost, i.e. one exact plant type may have a low water consumption but a high cost, while another can have a high water consumption and a low cost. This leaves the landscape designer conflicted between the two goals. Since two goals are involved, this is a multiple objective optimization problem. One way to solve these types of problems is by assigning different weights to each of the two criteria. This means the landscape designer would need to assign different importance factors for each of the two criteria in order to make the selection. For example, if the two criteria are equally important then the landscape designer would assign equal weights to each, i.e. 50% to each. If one is deemed 3 times as important then one of these goals would be assigned 25% while the other would be assigned 75%, and so on. However, since the actual values for the two criteria may vary (i.e. one would be in the hundreds and other in the tens only) we will need to normalize these values, which can be done using goal programming as will be explained later. Other approaches that do not rely on assuming weights can be utilized as discussed in the report (e.g. Pareto optimality).

There are also some constraints for the problem. From the point of view of this problem there are two types of constraints. The first type is constraints would be set on each of the plant types selected and are basically the requirements set by the landscape designer such as the height, color, shading, spread and blooming season. This first type of constraints limits the properties of the plant selected on an individual basis and as such can be called local constraints. They are basically filtering criteria for the database. Also a second type of constraint called global constraints can be set. These global constraints range the total selection of the plants and can only be determined after selecting all the plants for that particular project, such as the total coverage area of all the plants selected. These types of constraints are harder to deal with mathematically, than the selection criteria constraints set by the designer for each plant type such as the height, color, shading, spread and blooming season.

Another important factor to consider is that the goals of water consumption and cost can themselves be set as criteria. In that case, they would be set as the second type of constraints, namely global constraints. For example, the landscape designer may choose to find the exact plant types that minimize the cost while not exceeding a certain budgeted water consumption, or vice versa.

In the next section we will present the mathematical formulation of the problem specified above. The problem mathematical formulation is important to allow for efficient solution of the problem, especially if the number of individual exact plant types is large and the solution space becomes very large.

VI. MATHEMATICAL FORMULATION

The problem at hand can have different formulation depending on the exact intent of the landscape designer. The problem starts with a flat database of the plants, with a number of fields representing the various properties of the plants. One of the fields in the database includes the plant types and there would be k different plant types. In the simplest case the designer would like to select a particular quantity of each plant type that meets certain restrictions. We will use the notation $i_k$to mean the individual exact plant i of type k ($k = 1,2,3 \dots . M$), i.e. oak which is a type of deciduous trees. Therefore, for each plant type k of the M types, the designer would like to select a particular planti_k. Note that each of the k types has a total of Nk plants, i.e. there may be a total of 100 deciduous trees in that type and therefore if the deciduous tree category is number 3 for example, then N3= 100. As such there would be a total of $T = \sum_k^M N_k$plants in the entire database.

In particular, the designer would like to select a particular quantity Q_k from each type k for a total of K types of the M types in the database. In this simplest case the designer would like to minimize the water consumption and also minimize the cost. Each of the T plants has a cost C_{i_k} and water consumption W_{i_k}.

Equation 1: Mathematical Formulation

$$\min\left[\sum_{k=1}^{K}\left(A(C_{i_k} \times B_{i_k} \times Q_k) + B(W_{i_k} \times B_{i_k} \times Q_k)\right)\right] \quad (1)$$

Subject to

$P1_{i_k} \leq$ Upper Limit P1 …….(e.g. for k = 1,2,…..)

$P1_{i_k} \geq$ Lower Limit P1 …….(e.g. for k = 1,2,…..)

$P2_{i_k} \geq$ Upper Limit P2 …….(e.g. for k)

$P3_{i_k}$= Set Value P3, etc.

$$B_{i_k} = \{0,1\}$$

Where:

- i_k denotes the chosen set of plants
- B_{i_k} a binary variable indicating whether plant i_k is selected or not
- Q_k denotes the quantity of the plant
- C_{i_k} denotes the life-cycle cost of the plant
- W_{i_k} denotes the water consumption of the plant
- A denotes the preference weight allocated for the life cycle cost
- B denotes the preference weight allocated for the water consumption
- $P1_{i_k}, P2_{i_k}, P3_{i_k}$ ....the value of criteria P1, P2, P3, … for plant i_k

Note that P1, P2, P3, …. are set of criteria that needs to be met for the selected plants and can be used to set a range, an upper or lower limit only or even a specific value. This may be used for example for selecting plants that meet certain height restrictions or have a specific blooming season and so on. These criteria can be used for certain plant types (i.e. for k = 1,2,…..) or for all plant types (e.g. for ∀k).

The variables to this problem are B_{i_k}, which are binary variables to denote whether that particular plant is selected or not. By varying the different plant types to use (i.e. different B_{i_k}), the total value of the cost and water will change and we can select the combination that results in the best values.

Multi-objective optimization has been applied in many fields where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives. A multi-objective optimization problem is a problem that involves multiple objective functions. In mathematical terms, a multi-objective optimization problem can be formulated by assigning weights to the different criteria and then trying to minimize (or maximize) the combined values. The feasible set is typically defined by some constraint functions. This approach is used here and A and B are the weights allocated to the cost and water consumption respectively as can be seen in Equation 1.

VII. SIMPLE FILTERING AND SELECTION

The simplest form for the problem of selecting the plants is to choose from each type the exact plant type to minimize the cost and water consumption while meeting certain criteria. It is clear that equation 1 can be written as a linear sum of both terms, i.e. the minimum value for both terms is the minimal for each term separately. Also, the quantity term, Q_k can be factored out of the equation.

VIII. DYNAMIC PROGRAMMING SOLUTION

8.1. The Problem as a Knapsack Problem

This problem arises whenever there is a constraint in the water, cost or any other criteria that needs to be calculated across the entire database. As such the problem becomes a classical knapsack problem, where costs for example and water consumption values are given of the T plants in the database and we would like to select from these plants in a knapsack of a certain capacity (which represents the maximum allowable water consumption) to get the minimum total cost in the knapsack. This problem can also be formulated reversely, where the goal would be to minimize water consumption given an allowable cost.

In other words, given two fields in our database of plants, which represent the cost and water consumption associated with plants respectively and also given the maximum allowable water consumption which represents knapsack capacity, find out the minimum value subset of plants such that sum of the water consumption of this subset is smaller than an allowable consumption set forth earlier. Plants must be chosen wholly, i.e. you cannot break plants, either pick the complete item, or don’t pick it (0-1 property).

A simple solution is to consider all subsets of the plants and calculate the total water consumption and value of all subsets. Consider the only subsets whose total water consumption is smaller than the allowable. From all such subsets, pick the subset that meets the criteria on other fields (i.e. height, blooming season, etc.) as well as the one with the minimum cost value. This minimum cost value subset is the optimum.

To consider all subsets of items, there can be two cases for every item: (1) the item is included in the optimal subset, (2) not included in the optimal set. The, minimum value that can be obtained from the T plants is the minimum of the following two values. First, the minimum value obtained by n-1 plants and the allowable water consumption (excluding nth item). Second, the minimum cost value of nth plant plus the minimum cost value obtained by n-1 plants and meeting the allowable water consumption minus water consumption of the nth plant (including nth plant). If water consumption of nth item is greater than W, then the nth plant cannot be included and case 1 is the only possibility. This can be implemented in a recursive algorithm. The following is recursive implementation that simply follows the recursive structure mentioned above. This algorithm uses Dynamic Programming.

Dynamic programming is a method for solving a complex problem by breaking it down into a collection of simpler sub-problems, solving each of those sub-problems just once, and storing their solutions. A dynamic programming algorithm will examine the previously solved sub-problems and will combine their solutions to give the best solution for the given problem.

8.2. Programming Formulation

Dynamic programming is a method for solving a complex problem by breaking it down into a collection of simpler sub-problems, solving each of those sub-problems just once, and storing their solutions. A dynamic programming algorithm will examine the previously solved sub-problems and will combine their solutions to give the best solution for the given problem.

1. Run single objective optimization function for Life Cycle Costs considering all required design requirements/constraints. Determine minimum possible LCC (LCCmin).
2. Run single objective optimization function for Water Consumption considering all required design requirements/constraints. Determine minimum possible Water Consumption (WCmin).
3. If other objectives are sought repeat same step in (1/2).
4. Formulate as goal programming problem.

a. Calculate positive LCC deviation as the % of deviation from LCC goal:

dLCC = (LCC – LCCmin)/ LCCmin

b. Calculate positive Water Consumption deviation as the % of deviation from WC goal:

dWC = (WC - WCmin)/WCmin

c. Find the optimal design solution that minimizes the weighted deviation from goals:

Z= w1* d LCC + w2*dWC

Where: w1 and w2 are the weights for LCC and Water Consumption respectively.

8.3. Sample Problem and Solution (Use Case)

In this section we present a generic numeric example to illustrate the applicability of the developed system to solve such problems. Table 2 shows a small generic database composed of 10 records and some related fields. The most important fields are the cost and water consumption which show sample values for the different plants in the database. Also two fields indicative of other criteria are shown. Criterion A has a lower and upper limit and there is also another criterion B. In our example, criteria A is a numeric valued criteria, representing height, and criteria B is textual valued, representing the blooming season.

Table 2 : A numeric example of a plant database

Plant Number	Variables	Type	Water Consumption	Cost	Criteria A-LL	Criteri a A-UL	Criteria B
Palm 1	0	P	200	50	2	3	Sum
Palm 2	1	P	150	80	3	4	Win
Palm 3	0	P	300	30	4	4	Fall
Shrub 1	1	S	200	20	1	1	Fall
Shrub 2	0	S	150	50	1	1.3	Sum
Shrub 3	0	S	300	60	0.5	0.9	Win
Tree 1	1	T	200	80	2	3	Fall
Tree 2	0	T	150	100	3	4	Spr
Tree 3	0	T	300	120	2	3	Spr
Tree 4	0	T	150	90	3	3	Spr

In the data shown above the plant types is M = 3 (there are 3 types of plants, palms k =1, shrubs k =2, and trees k= 3) since we are going to select all the 3 plant types then K = 3 also. Additionally, $N_1 = 3$, $N_2 = 3$ and $N_3 = 4$ and therefore plant 2_3 denotes Shrub 3 for example.

A landscape designer is asked to design the landscape of a house, so he enters the following characteristics of the project at hand such as the Area of landscape (say $800m^2$) and the Location of land (Hardiness Zone, Cairo, Egypt (18-19)). The client shows that he is more interested in saving in irrigation more than the initial cost. So the landscape designer puts the following weights:

- Water consumption: 80% weight
- Cost: 20% weight
- Water price (per Liter): 0.78 EGP/Liter

The landscape designer then decides on the different categories of plants he needs, according to his initial design, so he enters the following inputs:

- 20% Trees, <u>Height:</u> 3 meters, <u>Bloom Season:</u> Spring
- 20% Palm Trees, <u>Height:</u> 3 meters, <u>Bloom Season:</u> Winter
- 60% Shrubs, <u>Height:</u> 1 meters, <u>Bloom Season:</u> Summer

The landscape designer then runs the optimizer. The program first filters the plants according to the constraints set by the landscape designer, then runs the optimizer and outputs the 3 most suitable plants in each of the 3 above plant types set by the landscape designer. The detailed steps of the optimization are shown as follows (Figure 1):

1. The first step in the dynamic programming algorithm is to break down the complex problem into smaller sub-problems.
2. This problem intuitively should be divided according to plant types, so in this problem each sub-problem will be solved to find the best solution within its type; i.e. The best shrub, best palm, and best tree, which suit the criteria.
3. After plants have been categorized according to their type, a filtration is run to remove the plants that do not match the criteria set by the architect.
4. The optimization is then run on the remaining data set for each plant type separately.
5. The output of the optimization will be shown as the best plant from each type. This way the result of the larger complex problem will be shown. (Figure 2) shows two selected options from the database.

(A)

(B)

(C)

(D)

Figure 1: Steps in solving the knapsack problem formulation using Dynamic Programming

A Pareto-optimality analysis is also performed to undertake multi-objective optimization without relying on the a priori assumption of weights. Pareto optimality determines a set of non-dominated solutions that achieve the least possible water consumption and lifecycle cost as shown Figure 3. All dominated solutions are automatically removed from the set of possible solutions. A dominated solution is defined as a solution that is known to be inferior in all optimization objectives to another non-dominated solution. For each non-dominated solution, the landscape designer can rapidly assess the most suitable design based on aesthetical preferences taking into consider sustainability objectives.

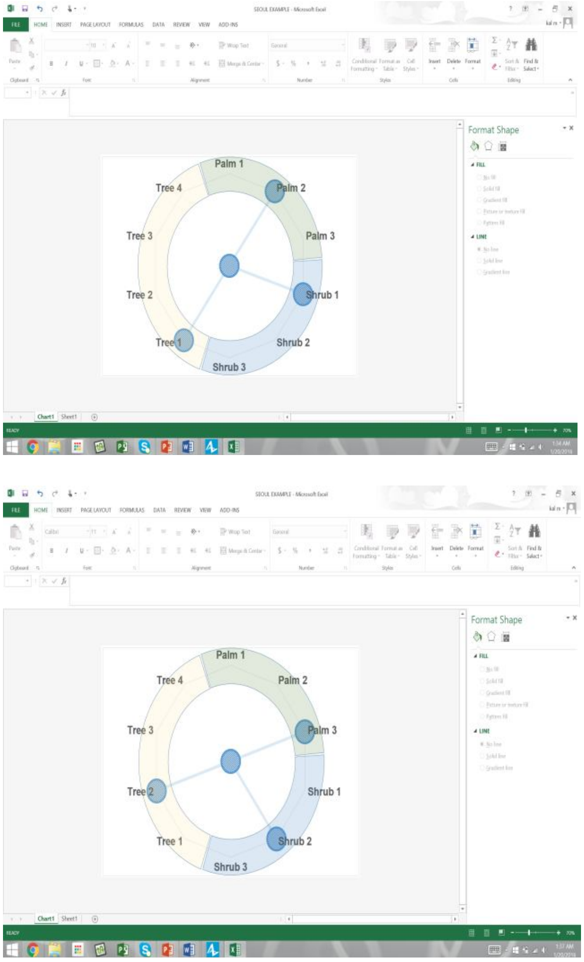

Figure 2: Two selected options from the database

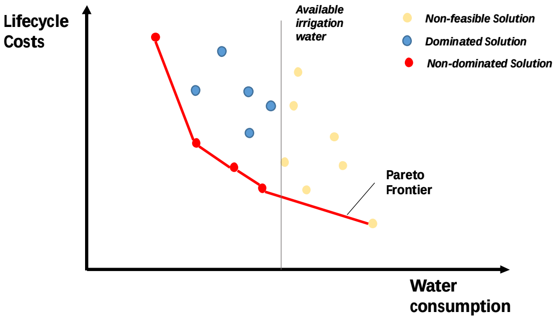

Figure 3: Pareto optimal frontier showing non-dominated solutions

CONCLUSIONS

The literature research on existing plants' databases in addition to the field research with architects, suppliers and contractors led to the following attributes to best represent the plants to be fed to the ENVO-LAND optimizer: Classification, Type, Genus, Species, Latin Name, Common Name, Arabic Name, Dimensions, Bloom Season, Design Usage, Life Cycle, Light, Salt Tolerance, Drought Tolerance, Irrigation/Water Demand, Cost, Maintenance, Hardiness Zone and Environmental Concerns.

Some of the major findings regarding building the ENVO-LAND database to collect the above attributes are shown below:

- None of the databases covered all the attributes and therefore, the ENVO-LAND database will be filled by combining data from multiple databases
- The easiest way to select the suitable plants for different geographies is by filtering the databases based on the hardiness zone
- Two of the important fields (based on the field research); cost and maintenance cost can only be filled through field studies or crowd sourcing.

The ENVO-LAND optimizer was built using the knapsack dynamic programming model; which allows for the rapid solving of the multi-objective problem to reach a set of plants that minimize the cost, as well as the water consumption. Further research include compare the performance of the knapsack dynamic programming optimization technique against other near-optimization techniques such as Genetic algorithms, and neural networks.

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