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Systematic Approach to Design with Nature

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1. Introduction

One of the main goals in the field of Environmental Design in the 21st Century should be to find objective and systematic design processes for the implementation of the concept of design with nature for large scale projects such as regional parks, residential villages, reforestation and green belts around industrial sites. The author also believes that to design with nature, one should design the way nature does. Nature designs in terms of natural laws rather than taste, personal preference or school of design. Some projects, however, involve man-made as well as natural laws and parameters. Fortunately with regards to site planning, surface modeling and site analysis software have been available by which the site can be analyzed and placements made based on topo-edaphic variables. For planting design, however, very little work has been done. In fact, to the author's knowledge only one system for urban forests has been developed (Kirnbauer et al, 2009) which uses climatic and soil data to select the plant palette. Plant placement, however, is not based on topographic variables.

2. The systematic approach

The approach mainly consists of choosing the suitable parameters and variables, based on which the design evolves more or less automatically. The choice of parameters and variables is the most important step and requires careful consideration and consultation. This is due to the fact that from here on, the design will evolve from the interaction of these parameters and variables and the designer's involvement will be minimal. In this chapter the systematic approach is first explained for site planning in general and then more specifically for planting design.

2.1 Site planning

The approach is demonstrated for site planning of a 38 ha villa complex on an undulating topography (Fig. 1) near Isfahan, Iran (by the author, in 1998) using the available surface modeling and site analysis modules of Landcadd. The procedure consists of three steps.

2.1.1 Step 1 – Determining the parameters and variables

The suitable range for each variable for the different design elements is determined. For the present project, three variables (based on the available data) were considered. Some examples are presented in Table 1.



Fig. 1. Topography of the 38 ha project site for a villa complex.

Design element	Variable		
	Slope (%)	Aspect	Elevation (m)
Parking lots	0-10		
Sports courts	0-10	N, NE, E (less wind)	<110 (less wind)
Vilas	0-15		>65
Hotel and restaurant	0-15	S, SE, SW (good view)	>110 (good view)
Mass irrigated tree planting	15-30		
Mass non-irrigated shrubs	30-45		

Table 1. Design elements and the corresponding classes of variables.

The three parameters considered were: Minimum distance of 15m between villa buildings, 8% maximum slope for the roads and 30 km speed limit (for the radii of road curvature).

2.1.2 Step 2 – Site analysis

Surface modeling and site analysis software generate aspect, slope and elevation variables from survey data (x, y, z) from project sites. They do this in terms of grid cells, the size of which is determined by the designer, based on the topography and the intended use of the site. Other variables such as soil depth can be added, using the elevation analysis (Sepahi, 2005). Figure 2 presents the classes (AutoCAD layers) for slope and elevation generated for the site using Landcadd software. Regarding aspect, the software generates nine AutoCAD layers for N, NE, E, SE, S, SW, W, NW and FLAT. A short review of the application of Remote Sensing to site analysis regarding topography, soil and plant cover is presented by Sepahi (2009).

2.1.3 Step 3 – Placement of the design elements

AutoCAD layers bearing the hatch patterns representing the suitable classes of slope, aspect and elevation for each element were ‘frozen’, which led to the disappearance of their hatches from the computer monitor. This resulted in patches of land with blank (not hatched) grid

cells in which the AutoCAD blocks representing the respective elements (such as villas) were inserted. After laying out the access roads to the patches, finer adjustments, such as alignment of elements along the roads were made. For the hotel and restaurant, for instance, the AutoCAD layers corresponding to the suitable attribute (Table 1) i.e. SLOPE-0-10, SLOPE-10-15, ASPEC-SOUT, ASPEC-SWST, ASPEC-SEST and ELEVE-110-MAX were frozen resulting in a few options, of which the most suitable were chosen. The blank patches would be more clearly visible if all the AutoCAD layers were assigned one color such as grey. It should be noted that Landcadd has a command by which, for a given point on the site, the scope of the observable terrain is indicated.

The layout of the roads was a function of maximum allowable slope, speed limit and the topography. Civil engineering software is available for such a task. For a preliminary road layout, however, a simple procedure can be used. A circle is drawn at the origin (O) of the road (Fig. 3-a) with radius $R = CI/MS$, in which CI is the contour interval and MS is the maximum allowable slope (e.g., 0.08 for 8%). The circle intersects the adjacent contour line at two points (A and B). The point which is to the direction of the destination – point A in this case – is chosen and an AutoCAD polyline is drawn from the origin to it. The circle is then moved to this point and the process is repeated. At locations where the slope of the land is less than the MS, the circle will not intersect the next contour and any line drawn will have a slope less than MS. At the end of the road layout, the FIT Command of AutoCAD is used to smooth the path of the road (Fig. 3-b). Finer modifications are then made regarding the radii of the curves based on the speed limit (indicated by an arrow in Figure 3-b). This approach to road layout does away with the common disagreement between the landscape architects and engineers, i.e. aesthetics vs. engineering principles. In fact the author doubts if there is such a thing as an aesthetic road that is not soundly engineered.

The systematic approach provides the bulk of the conceptual site planning. Final decisions and refinements will eventually be made on the site. The main advantages of the approach are: conserving the natural topography by avoiding massive land leveling; organic distribution of the elements (naturalistic aesthetics) and the elements fitting comfortably in the terrain. In Figure 4 the site planning for the villa complex is presented.

2.2 Planting design

To the author, design with nature with respect to planting design, implies achieving three objectives: *conserving nature*, *establishing a sustainable ecosystem* and achieving a *natural appearance*. Conserving nature involves many issues. Those related to this topic are: maintaining the site's topography and contour planting to reduce erosion.

Sustainability is a complex concept. A version sufficient for mass planting involves:

- selection of a plant palette suitable for the site's climate and soil
- placing individual plants at suitable locations within the site
- ensuring compatibility among the species
- avoiding extensive plant loss due to natural causes and attracting varied wildlife through a diverse plant palette

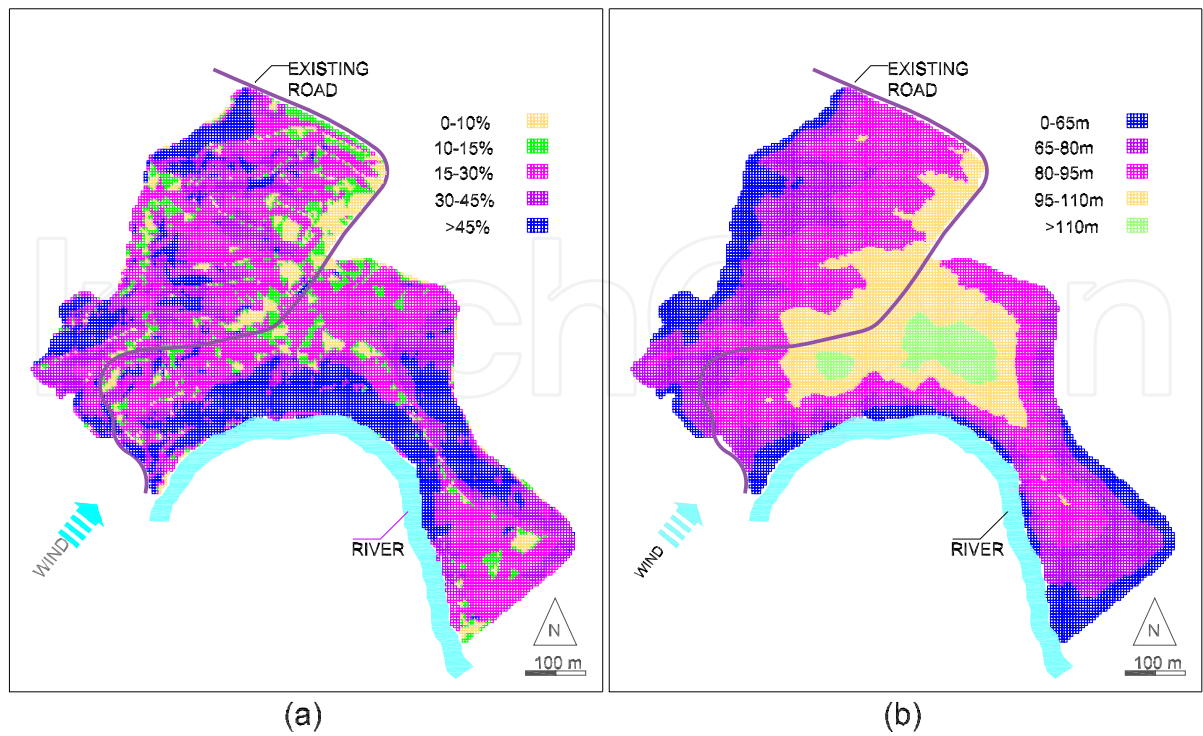


Fig. 2. Slope analysis (a) and elevation analysis (b) of the 38 hectare project site.

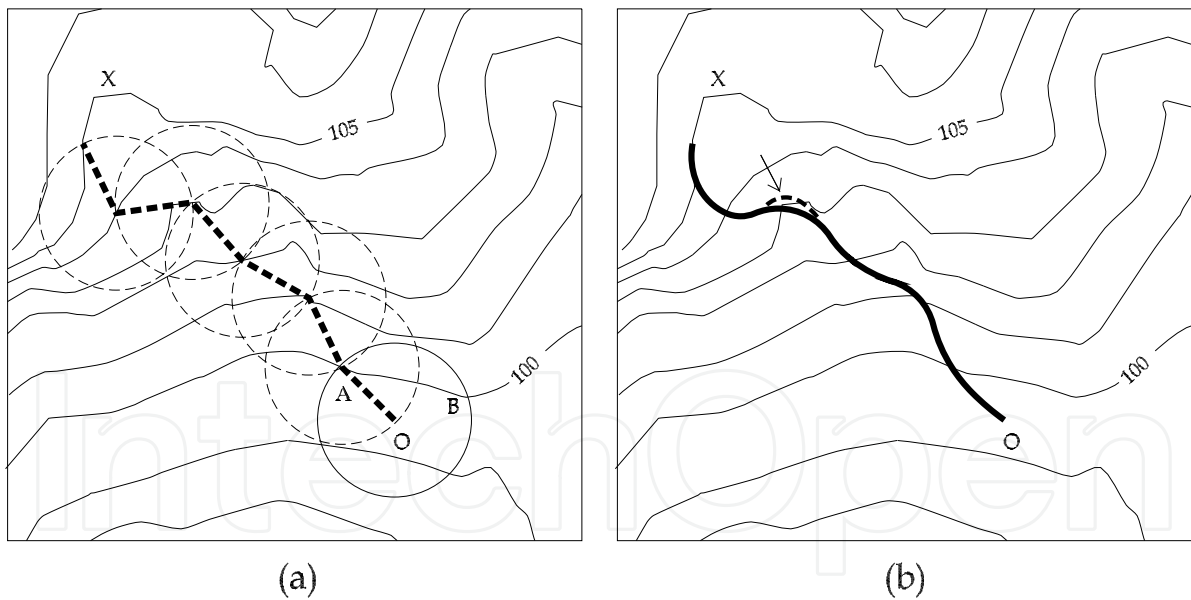


Fig. 3. Road layout from the origin O to the destination X.

Natural appearance is an issue related to aesthetics and involves:

- diversity of species
- visual association of species (seen together in nature)
- unity, brought about by one species being dominant
- organic distribution of the species, in contrast to geometric patterns
- blending of the site into the natural surroundings

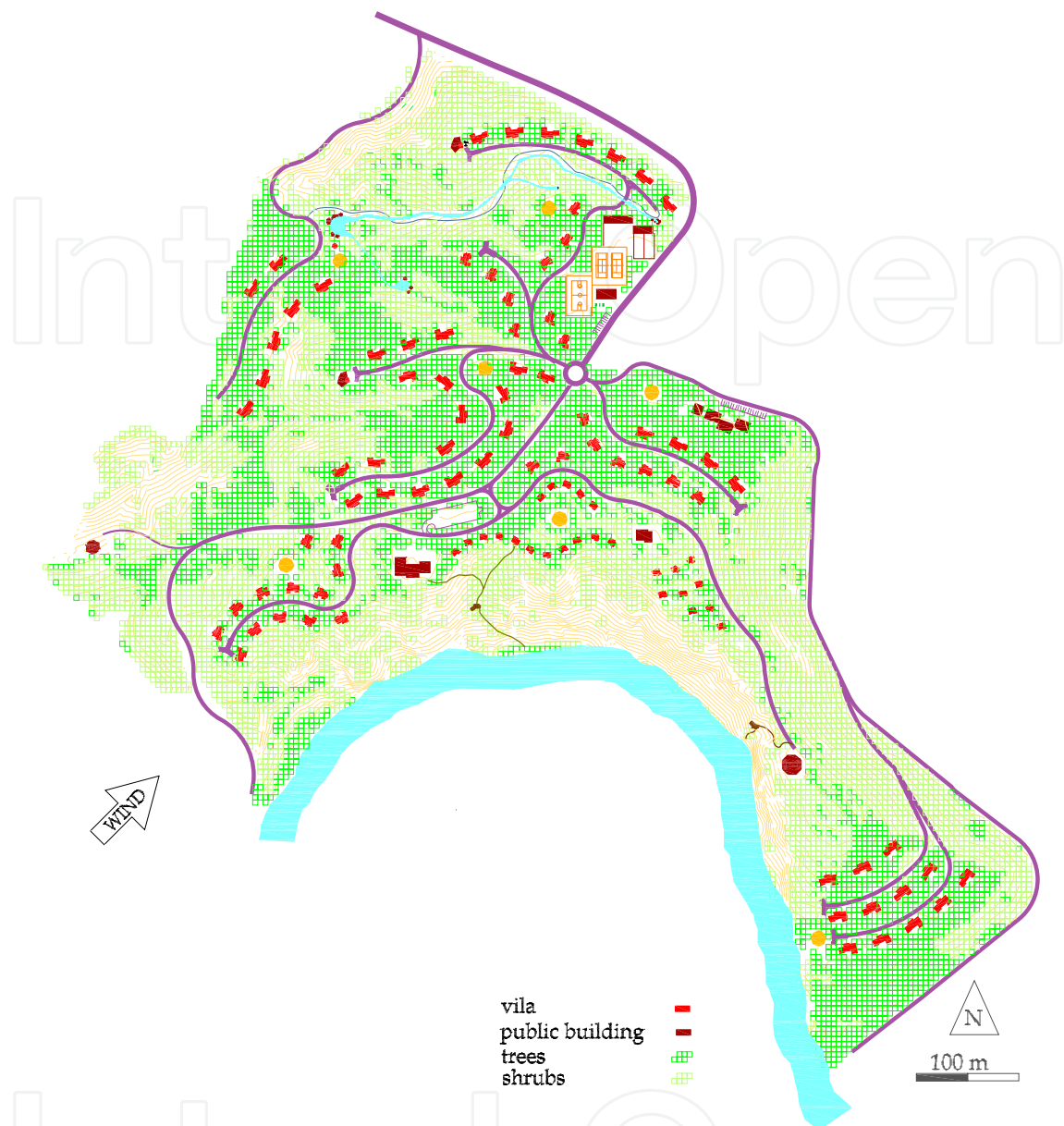


Fig. 4. Site planning of the 38 ha villa complex near Isfahan, Iran.

The above objectives can be realized by selecting a plant palette from a native (model) plant community suitable for the climate and soil of the project site, and placing the individual plants based on the specific topographic and soil characteristics of the locations within the site. The author believes, as some other workers cited by Thompson (1998) that if landscape planning is undertaken along ecological lines, the aesthetic aspects will be taken care of automatically. Not only should there not be a “tension between aesthetics and scientific foundations in Landscape Architecture” as Harding Hooper et al (2008) put it, application of scientific findings should be an integral part of the design process.

Three methods were presented (Sepahi, 2000, 2005, 2009, in print) to arrive at an objective and systematic design process for planting designs resembling native plant communities. The approach can be summarized in four main steps. The steps, however, do not correspond

to those in the respective articles. The three methods differ only with respect to Step-3. The main purpose of the present chapter is to present an overall view of these methods. Hence, the same set of data with a few variables and species (Sepahi, in print) is considered to briefly explain the three methods. For discussions on the justification, literature review and mathematical details, the reader is referred to the original articles.

2.2.1 Step 1 – Site analysis of the project site

For demonstration, Landcadd’s surface modeling and site analysis modules (Eagle Point, 2005a and 2005b) were used to generate data on aspect, slope and elevation along with soil depth, using survey data from a 14.4 ha project site (Fig. 5). Topo-edaphic data for the first row of grid cells (cell N° 1 at the top left of the figure) is presented in Table 2.

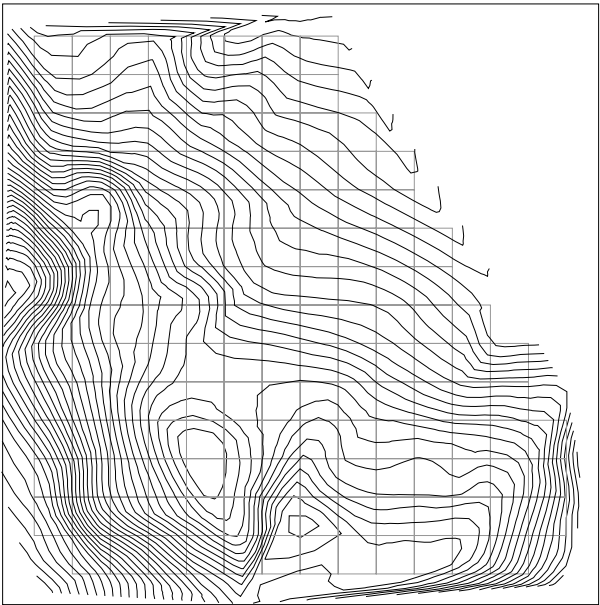


Fig. 5. Topographic map of the 14.4 ha project site with 30x30 m grid cells and 2m contour intervals.

Grid cell N°	Variable			Soil depth (cm)
	Aspect (degree)	Slope (%)	Elev. (m)	
1	45	25	1495	130
2	315	15	1495	150
3	0	15	1495	130
4	90	25	1495	110
5	45	25	1495	90
6	0	15	1485	50
7	0	15	1485	50
8	0	15	1485	50

Table 2. Topo-edaphic variables of the first row of grid cells in Fig. 5.

2.2.2 Step 2 – Selecting a plant palette

A plant palette from a native (model) plant community suitable for the site’s climate and overall soil characteristics (with supplementary irrigation, if required) is chosen. For demonstration, a plant palette of seven species was chosen from an Englemann Spruce-Subalpine Fir biogeoclimatic zone in the Boston Bar area, B.C., Canada, as the model community. Data from 10m-radius sample plots, provided by the Resource Inventory Branch, Ministry of Forestry, Victoria, B.C. was used (Table 3).

2.2.3 Step 3 – Determining species composition of the grid cells

In this step the expected percent crown cover (abundance) for each species for every grid cell is determined. This is done differently in the three methods explained below.

The Regression Method - The method (Sepahi, 2005) can accommodate any number of environmental variables and species, thus different levels of biodiversity and natural representation can be attempted. For each of the seven species (Table 3) a multiple regression of the percent crown cover on the topo-edaphic variables is run. The format of the resulting seven equations would be:

$$Y = b_0 + b_1X_1 + \dots + b_nX_n$$

(1)

in which Y represents the expected percent crown cover (EP), X the value for the topo- edaphic variable and b the corresponding partial regression coefficient. The values of the topo-edaphic variables for each grid cell (Table 2) are inserted in every one of the seven multiple regression equations and the expected percent crown covers for the seven species for the grid cell are calculated. These are later translated into the recommended number of trees in Step 4.

The Least Difference Method - With the imminent availability of a large volume of data from model communities through Remote Sensing technology, the Least Difference Method

Topo-edaphic variables					Species ¹ percent crown cover								
Sample Plot No	Aspect (degrees)	Slope (%)	Elev. (m)	Soil depth (cm)	ABIELAS	ALNUCRI	ALNUVIR	LONIINV	PICEENE	PICEENG	PINUCON	TS	TA
1	78	2	1354	141.0	17.9	0.0	2.3	0.0	0.0	26.7	0.3	47.2	131.9
2	165	12	1275	106.0	16.0	0.0	10.0	0.0	0.0	5.0	55.0	86.0	141.2
3	353	70	1330	102.0	12.3	0.0	0.0	0.0	0.0	3.0	0.0	15.3	62.5
4	350	4	1090	149.0	0.4	0.0	23.0	0.0	5.0	0.0	14.0	42.4	46.3
5	352	15	1200	55.0	38.0	0.0	1.0	3.0	0.0	38.0	0.0	80.0	90.2
.
.
36	34	23	1230	160.0	38.0	0.0	0.0	0.0	0.0	8.0	10.0	56.0	146.6

1: Abbreviations used by the Ministry of Forestry, BC, Canada
TS: Total percent crown cover of the selected seven species
TA: Total percent crown cover of all the species (originally recorded) in the sample plot

Table 3. Data from Englemann Spruce-Subalpine Fir biogeoclimatic zone in, B.C. Canada.

(Sepahi, 2009) was presented that emulates nature more closely and is not based on a mathematical model. The approach is based on a simple argument that if two patches of land are similar, plant composition suitable for one (a sample plot in the model community) is also suitable for the other (a grid cell on the project site). Topo-edaphic variables of each grid cell (Table 2) are compared with those of all the 36 sample plots in the model community (Table 3) one plot at a time. The sample plot, most similar to the grid cell is chosen and its percent crown covers are assigned (as EPs) to the grid cell. The method can accommodate any number of environmental variables and species.

The Variable Classification Method- This method (Sepahi, 2012) draws on the fact that plants respond to ranges, rather than to specific values of environmental variables. It is not based on a mathematical model and does not involve statistical analysis. Although it can be fully computerized, it can also be applied semi-automatically, using the available site analysis software. The values for the different variables in Table 2 and Table 3 are grouped into different classes. The method is suitable when few variables and classes (e.g. low, medium and high) are considered.

Regarding aspect, Landcadd generates nine aspects: N, NE, E, SE, S, SW, W, NW and FLAT. The ideal way to reduce this number would be to customize the software to generate five aspects of NE, SE, SW, NW and FLAT. This is based on the fact that in the Northern Hemisphere, the growth gradient is along the NE-SW axis rather than the N-S axis (Urban et al., 2000). A simpler and close enough alternative is to merge every two consecutive aspects (AutoCAD layers) to produce four aspects of: N-NE, E-SE, S-SW, W-NW plus one FLAT. This approach was followed for the present demonstration. In Table 4 the resulting classes for the variables in Table 2 are presented. Although a bit more involved (see Sepahi, 2012) in principle, the percent crown covers of the sample plots are allocated to the grid cells with matching topo-edaphic variables.

Grid cell N°	Variable			
	Aspect (degree)	Slope (%)	Elev. (m)	Soil depth (cm)
1	N-NE	L	L	H
2	W-NW	L	L	H
3	N-NE	L	L	H
4	E-SE	L	L	H
5	N-NE	L	L	H
6	N-NE	L	L	L
7	N-NE	L	L	L
8	N-NE	L	L	L

H and L: represent high and low classes respectively.

Table 4. Topo-edaphic variables of Table 2, classified into different classes.

2.2.4 Step 4 – Determining plant number and placement

The expected percent crown covers calculated in step 3 (by any of the three methods) are translated into the number of plants for the seven species using equation 2.

$$N = \frac{EP \times GA \times TA}{100 \times CA \times TS \times \cos \alpha} \quad (2)$$

Where, EP is the expected percent crown cover for the species, GA is the area of a grid cell, CA is the crown area (from the crown diameter assigned to the species), TA and TS are from the last two columns of Table 3 and α is the angle of the slope of the grid cell.

Once the numbers of the plants of the species for the grid cells are determined, different schemes can be used for their placement. For demonstration, one type of contour planting is explained here. The MEASURE command of AutoCAD is used to mark the contour lines at the desired intervals (Fig. 6). The icons (AutoCAD blocks) for the species are, then, placed at random on contour lines within the grid cells in the drawing. Figure 6 presents the placement of icons for cell N°5, using the Regression Method.

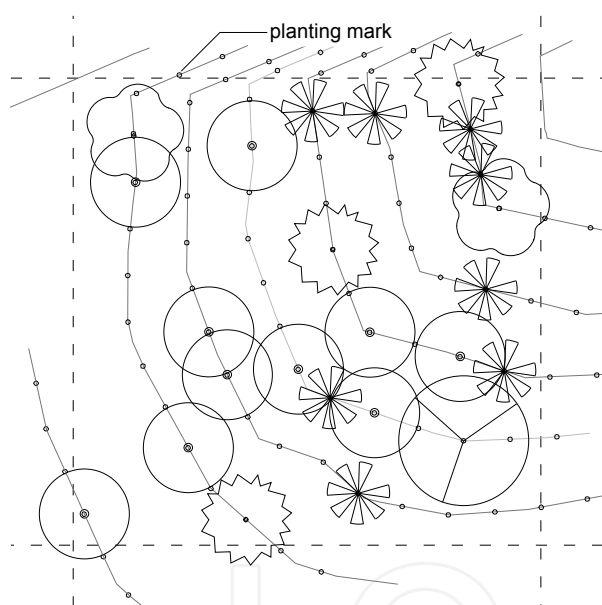


Fig. 6. Plant composition of the grid cell for cell N° 5 using the Regression Method.

The choice of the Regression Method, the Least Difference Method or the Variable Classification Method is based on the number of sample plots, number of variables and the mode of data processing (Table 5). Data processing could be automatic (using a computer program) or manual (using a spreadsheet).

The three Methods place individual plants based on topo-edaphic variables, thus realizing the ecological potential of the project site more fully than the present common practice. They draw on an already available wealth of data on plant communities in forestry departments. They provide an organic distribution of species for the bulk of the planting. Designers can make necessary changes in specific areas (e.g. around buildings, sitting areas) using a larger or different plant palette. Designers can also use their ingenuity for modifications or attaining different levels of natural representation. The following are a few examples:

- taking into consideration the uneven age distribution in the model community
- bio-geographic planting (Kingsbury, 2004), i.e. aiming at as complete a representation of a natural plant community as possible
- achieving organic distribution for plant palettes of commercial (non-native) cultivars

Method	Number of samples	Number of variables	Automatic data processing
Regression	low	any	required
Least Difference	high	any	required
Variable Classification	high	low	not required

Table 5. Recommended methods for different number of sample plots and topo-edaphic variables and modes of data processing.

For the reader who would like to try the methods, a few recommendations are presented. For the Least Difference Method, adjust the elevations from the project site so that the minimum elevation is the same as the model community. For both the Regression Method and the Least Difference Method, convert aspects into Annual Direct Incident Radiation and Heat Load, using the procedure proposed by McCune (2002). Apply Equation 2 to all the three methods, except for the cases where TS for any of the sample plots in the model community is zero. In that case the equation should be modified as follows:

$$N=\frac{EP\times GA\times DF}{100\times CA\times \cos a}\tag{3}$$

In which, DF is the density factor calculated as the average of TA divided by the average of TS (last two columns of Table 3). It is used to account for the fact that not all the species in the original sample plots were included in the design.

2.3 The role of scientific research

The present trend in design emphasizes issues such as social responsibility, sustainability, environmental responsiveness and human health (Milburn et. al., 2003). In the systematic approach to design, the quality of the outcome is determined by the reliability of the parameters and variables chosen. Such issues require incorporation of research into the landscape design process. The research, basically a literature review, taps into the available body of knowledge acquired through scientific research. Some advances in the field of Landscape Architecture in areas such as irrigation, soil amendments, new cultivars and computer aided design have been due to the scientific and technical achievements of other disciplines. However some information, especially for the implementation of the concept of design with nature, might require studies which are not of common interest to the other disciplines. These have to be dealt with by scientific research within the profession. For instance, more work could be done to increase the accuracy of the planting design methods

mentioned above. In the Regression Method, interaction (statistical) between topo-edaphic variables could be considered, or transformations (e.g. logarithmic) on the variables could be tried. With respect to the Least Difference Method, other analysis for determining the relative importance of the different topo-edaphic variables in species distribution should be attempted. More work on combining some of the topo-edaphic variables into ecologically relevant predictors, such as soil fertility, would help to reduce the number of variables.

Some of the problems might be unique to specific projects. In a green belt project around the 3000 ha Mobarekeh Steel Mill Complex in Iran, the author was faced with a number of questions regarding the choice of the species suitable for the calcareous soil of the site, tolerant to the mill's pollutants and their irrigation requirements under the site's arid climate. Also of interest was the relative efficiency of the species in removing the pollutants from the environment. Thus the author in cooperation with two colleagues, an irrigation and a soil scientist, started a long term experiment involving 648 treatments (factorial combination of 72 species, 3 levels and 3 intervals of irrigation). The actual mass planting at the mill was to be carried out over a number of years. As new results were obtained from the experiment, modifications were made in the upcoming plantings.

The above passage pivots on the phrase 'scientific research'. One can get into a long discussion regarding the definition of scientific research, including basic and applied research. For our purpose, let us adopt a practical definition and consider scientific research as one which is accepted by scientific societies for publication. Such societies require that the results of experiments be accompanied by a statement of the probability of the validity of the results (denoted by * or **, indicating 95 or 99% levels of confidence). Such a statement can only be made if there is an estimate of the experimental error, obtained through the application of statistical analysis to the data. The analysis in turn, can only be made on data obtained based on a statistical design. Such an approach to research is imperative when a number of variables (controllable, uncontrollable or unknown) besides the variables in question, affect the results of the study. This necessity was first felt at the Rothamsted Agriculture Research Station in the 1920s which led to the invention of the science of Statistics by Sir R.A. Fisher. Although initially developed for agricultural research, it became widely used in almost all other fields of research.

To bestow research in the field of Landscape Architecture with such quality, it is necessary to incorporate the required skills in the curriculum. To this end the Masters Program should be divided into two sections:

1. Urban Design – the extension of the undergraduate program
2. Rural Design – with focus on projects involving nature at a large scale

The distinction between the two sections will be based on the relative emphasis placed on *innovative creativity* versus the *artistic creativity*. In the Rural Design, emphasis should shift more towards the innovative creativity which enables the future designers to deal with the various problems that nature with all its complexities presents, to devise new

techniques and carry out research projects that add to the body of knowledge in the profession.

The modification of the curriculum would involve incorporation of two courses in statistics. In the last term of the undergraduate program, the students should take an introductory course in statistics offered at the Departments of Statistics. This course can be elective, for those who expect to continue their post graduate studies in Rural Design. In the first term of the graduate program, the students of Rural Design should take a course in design and analysis of the experiments, known as Statistical Design. The statistical design course covers the application of statistics to the different types of experiments or surveys pertinent to the specific field of study and is usually offered within the respective department. Of course, the students would also take the necessary courses pertinent to nature, depending on their theses projects.

In the undergraduate program, being bold and daring (appreciated for urban designs) is encouraged. Exposure to scientific research methods leads to a more cautious, sensitive, respectful and humble attitude towards nature and controls the overuse of the so called artistic license. It would be helpful, if a reference manual on the application of statistical designs to Landscape Architecture research is put together.

The application of computers to scientific research is well known. In fact thanks to the computer, research workers (including the author) have been applying the statistical analyses to their data without remembering the details of the calculations involved. With respect to landscape design, once a process is based on laws, the logical next step would be to computerize it. However, the computer is not just to speed up the process; rather it is an integral part of the decision support systems. This is due to the fact that in the case of planting design, for instance, a number of variables (more than the three conceivable Cartesian coordinates) are involved, which mathematically can be considered. Moreover, challenging as it is to envisage the combined effects of a number of variables for placing individual plants from different species, applying it manually to thousands of individual plants would be a monumental task

3. Conclusion

Nature is already under heavy pressure from over population and cannot endure more hammering by designs incompatible with nature. Availability of a systematic approach reduces the occurrence of such designs. There are also a number of advantages in the systematic approach for the designers themselves:

- Confidence in the outcome - Since the best possible locations are determined for the design elements, there is no uncertainty, doubt and indecisiveness during the design process.
- Automation - The approach can be computerized, resulting in accuracy and speed
- Defendability - The questions raised by juries, regarding large scale projects, are mainly with respect to issues such as placement of the design elements, impact on nature, ease of implementation and cost, rather than the aesthetic aspects. These are all the issues

based on which the parameters and variables were initially determined. Placement based on topo-edaphic variables, by minimizing land leveling would address such issues.

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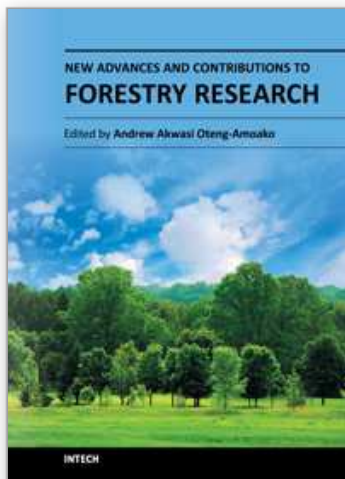
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New Advances and Contributions to Forestry Research consists of 14 chapters divided into three sections and is authored by 48 researchers from 16 countries and all five continents. Section Whither the Use of Forest Resources, authored by 16 researchers, describes negative and positive practices in forestry. Forest is a complex habitat for man, animals, insects and micro-organisms and their activities may impact positively or negatively on the forest. This complex relationship is explained in the section Forest and Organisms Interactions, consisting of contributions made by six researchers. Development of tree plantations has been man's response to forest degradation and deforestation caused by human, animals and natural disasters. Plantations of beech, spruce, Eucalyptus and other species are described in the last section, Amelioration of Dwindling Forest Resources Through Plantation Development, a section consisting of five papers authored by 20 researchers. New Advances and Contributions to Forestry Research will appeal to forest scientists, researchers and allied professionals. It will be of interest to those who care about forest and who subscribe to the adage that the last tree dies with the last man on our planet. I recommend it to you; enjoy reading it, save the forest and save life!

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