Using 3D Simulation, CAD, and Image Processing Techniques in Golf Course Management and Redesign

A Terminal Project

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ABSTRACT

Computer aided design and image processing are important tools for graphical representations of landforms. This thesis explores the use of 3D simulation, CAD and Image Processing Techniques for the evaluation of Long Range Golf Course Management and Redesign programs. The sites selected for this study are the Ohio State University Golf Courses.

The Ohio State University Golf Courses comprise a major recreational and sports facility located near the University's main campus in Columbus, Ohio. The facility includes two courses, both are considered among the most heavily played in Ohio. Maintaining and enhancing the existing design, in an environmentally sensitive and appropriate manner within the constrains of increasingly limited fiscal resources, is a major goal for the future. This project, using CAD, and image enhancement techniques, describes a prototype process for meeting such a goal. It documents the entire process of creating 3D-databases and simulation images, and examines methods of using such techniques for evaluating golf course management and redesign options by groups faced with approving such alternatives.

To work with and explore methods for using computer systems to visualize three dimensional environments is very important, not only for the individual
designer, but also for the Landscape Architecture profession and the various client or user groups for which landscape architects work. It is significant to investigate how these tools should and can be used in the process of developing a prototype process for a Golf Course Management and Redesign program.
CHAPTER I
INTRODUCTION

BACKGROUND

The Ohio State Golf Course Greens Committee is currently establishing long and short term maintenance and capital improvement (course enhancement) goals. A major change in the maintenance routines will occur next year, when state laws will prevent taking organic waste materials to landfills, because 50 percent of the existing disposal sites will be closed within the next 50 years. The handling of these materials will be an important challenge. Also only 70 percent of the Ohio State University Golf Courses are actually needed for playing golf, but at present nearly the entire tract of land is mowed at all times. At present, the Management Groups in the nation do not seem to have a clear position on these matters.

The computer is a valuable tool in visualizing design alternatives because it renders mathematically correct close to photo realistic representations of real world images. Accuracy, speed and the ability to view objects from every angle gives the computer an advantage over ordinary manual drawing techniques.
STATEMENT OF PROBLEMS AND OBJECTIVES

The scope of this project is limited to a prototype 3D, CAD, and video enhanced images for use in Long Range Golf Course Management and Redesign programs. Computer based 3D simulation and image Processing Techniques will be used to examine and evaluate the visual impacts of various landscape developments at the Ohio State University Golf Courses. The project will attempt to accomplish three major goals by using image processing techniques:

1. In order to maintain or enhance the playability and the beauty of the courses, new or replacement trees must be planted. The project will develop a series of prototype simulated images to determine which may be most effective in helping the Greens Committee study and evaluate tree location alternatives.

2. A second goal of this project will be developing prototype simulations and images for examining the desirability of proposals to enhance the playability and beauty of the courses through additional or alternative water features and new planting arrangements to achieve appropriate spatial characters, central views, and buffers around the boundary of the courses using CAD based 3D simulations, and image Processing Techniques.
3. The third goal is to develop a prototype process for using 3D CAD simulations, CAD Data bases and Enhanced images in maintenance routines which create a more naturalistic look of the courses.

APPROACH

To accomplish the objectives of the project 3D modeling, CAD, and video image enhancement techniques are being used. The Long Range Golf Course Management and Enhancement programs needs to be understood and desirable design applications selected.

AutoCad (ACAD) and DCA software will be used for 3D modeling and site design, and New Image (DOS platform) for the development of photo realistic images used to explore the visual changes to the golf courses. The computer will be very helpful for developing a prototypical program for evaluating design alternatives due to its ability to create mathematically correct 3D images. It will be possible to judge future design alternatives in terms of an accurate and effective evaluation of their impacts on the existing conditions. The created data files will add to the Long Range Golf Course Management and Enhancement program, because it will be easily accessible and understandable for everyone involved in Golf Course management. The only existing data on the golf courses are 2D maps showing contour lines and spatial data of greens, fairways, trees, bunkers, lakes, and roads. These maps were converted to digital
format data bases. The digital data base was used to create a three-dimensional digital Terrain model (DTM), of existing conditions. This model will become the basis for the design exploration necessary to meet the goals stated above. The next step was to scan slides of the existing conditions of the site into the computer, then match these images with 3D images generated by ACAD using the digitized drawing database, and then modified to show the impact of proposed changes.

In order to involve the Greens Committee and Course Management Staff in the decision making process and to meet the projects stated goals, several meetings were necessary in which financial limitations, current maintenance routines, existing and future problems will be discussed. It is anticipated, that the completed work will be presented by Prof. Carpenter to the course management team, - Coach Brown, Gary Rasor, Jim Jones, the Athletic Department and the OSU Greens Committee - which will evaluate proposed changes by viewing images of the courses.

The results of the project are divided into 2 parts:

1. Existing appearance of the courses: a 3D-model of the entire courses and computer generated 3D images of selected fairways of major importance.
2. Proposed appearance of both courses: designed 3D-models of important parts of the courses and images that will show the proposed character of the designed areas.

The proposed methodology will be used to show how computer technology, especially 3D simulation and video image enhancement, can facilitate the decision making process of the Greens Committee and Course Management Staff.

LITERATURE REVIEW

The review of literature is divided into four areas:

Computer Aided Design References, Image Enhancement References, golf course design references, and technical golf course maintenance References.

1. References to CAD

Computer modeling techniques for natural environments have been used by landscape architects for the last three decades. Upon completion of the drawing database the generated models can be altered to represent any desired design solution.

Articles discuss state of the art of software and hardware in computer aided design. Speed, database management, storage capabilities, and 3D modeling are the most frequent topics covered. The literature provides insight on the use of computer technology in large and small scale projects.
The use and generation of wire frame drawings and shaded surface models is explained in great detail. Metzger for example describes in his article the use of computer technology and 3D simulation in an Aspen Mountain Ski Area (Metzger, p. 34). He portrays the accuracy of the simulation and its input on the decision making process. Today most landscape architects still use two dimensional plans and elevations to analyze their design concepts. Three dimensional drawings are often created for presentation purposes and have therefore no impact on during the design phase. Visual impact studies, however, need to be conducted in the third dimension to be effective. Computer graphics have been developed to make three-dimensional design relatively easy to achieve. These computer techniques help designers and clients understand space and proposed environmental changes to come to the best possible solutions.

J. Kulak, “The case for CADD”, states: ... computers enables the designer to “know” the activities of a site, illuminate to a greater degree that site’s potential. Visual analysis projects require simulations of perspective views of landscapes. Data entry processes are time consuming operations which make the generation of these models burdensome (Friedman, p. 23). Still, it is desirable to explore computer three dimensional modeling techniques because it enables more people to become involved in the decision making process (Orland, p. 58)
Suspected missing page 7.
2. References to Image Enhancement

Video image processing techniques enable designers to modify images in a creative way. "Image editing offers a major advantage to those simulating future developments, large or small, for presentation to public audiences (Orland, p. 58). Images can be captured from photographs, video tapes, or actual scenes through video cameras. The lack of sharpness (resolution) in the captured image allows the editing to proceed faster in the knowledge that small errors in the final image will be less visible (Orland p. 58). Beyond producing good quality, realistic simulations, the format offers extensive possibilities in terms of their incorporation into site analysis processes.

Studies about technology that combines artistry with computer application to create realistic full color schemes of proposed projects, that have an impact on the amount of viewer interpretation have been conducted (Thorton, p.289). Technology and use of painting programs such as TARGA/TIPS or New Image are explained and evaluated in terms of their effectiveness. Orland for example discusses in his article the help of Image processing techniques for creating visual impact studies of dams and the usefulness of mathematically correct real world images in the decision making process (Orland, p. 125)
The generation of realistic video images requires artistic skill of the operator. To capture images on screens is a relatively easy process compared to the editing process, which is still tedious and relatively inaccurate. Still, the advantage of such techniques during client presentations and design processes is tremendous. The outstanding benefit is that it puts the designer's speculations into the client's language (Orland, p. 78).

3. References to Golf Course Design

The most important documents in this area deal with the approach to Golf Course design for the development of prototypical alternatives especially towards ecologically based designs. Changing laws force more and more golf course management groups to explore management alternatives and redesign of parts of courses to meet future standards (Rulewich, p. 12). Older courses often face the challenge to preserve initial site designs and spatial characters that are, in many cases, endangered due to the limited life span of trees (Kahler, p. 42). Other aspects is the evaluation of golf course designs, that take a more natural approach. The treatment of wetlands, out of play areas, and the replacement of trees are being addressed. Wetlands have never really been a concern in golf course design and management. According to Poellot, "The need for expertise as golf's grows globally," ...the fact that a portion of the course might intrude on a wetlands area was more of a technical question than a philosophical or and environmental issue.
Out of play areas are often very well maintained. The treatment of these areas is the focus in, for example, Teresa Stroud’s article “Rough and wild: Using wildflowers on golf courses”. According to Stroud, a link to nature has become the hallmark of some of the better courses in the nation, wildflowers can be used to accent out-of-play areas.

4. Reference to technical aspects of golf course design

Studies show, that currently used maintenance routines, for example the treatment of organic materials, the use of herbicides and fertilizer, or irrigation techniques are not meeting future standards. The exploration of alternative maintenance routines is necessary. The treatment of leaves and other natural materials is becoming a major issue. According to Bob Tracinsky, “Golf course composting and the recycling issue”, organic materials take us as much as 20 percent of this country’s total landfill space. Because landscape waste can be recycled on site, it is become the target of many new laws aimed at saving valuable landfill space. Mulching mowers, the introduction of composting operations and the long term effects of the use of different grass varieties are being discussed. The return of grass clippings and other organic materials to the lawn and eventually to the soil has always been considered to be a naturally accepted part of maintaining a lawn by the true turf experts (Perry, p. 30). Various sources explain different long and short term maintenance routines and their importance for ecologically based golf courses.
According to Dan Mackey, "Golf courses design maximizes grass potential", perhaps the most unusual aspect of design is the variety of turf grasses and adaptation of native vegetation into the landscape design. More emphasis is put on the development of grasses that need less maintenance and have therefore positive impact on the environment.
CHAPTER II

CASE STUDY- The Ohio State Golf Course

PROJECT DESCRIPTION

The Ohio State University Golf Course is a major recreational and sports facility located near the University's main campus in Columbus, Ohio. The facility includes two courses, both are considered the most heavily used in Ohio. Management and maintenance techniques currently used at The Ohio State University Golf Course need to be evaluated in terms of their effectiveness on maintenance, environment and aesthetics. Both increasing costs of upkeep and changing environmental laws make it necessary to explore alternatives to the currently used maintenance and management practices. Computer three-dimensional modeling and video image enhancement techniques will be incorporate in the process of evaluating these alternatives. Maintaining and enhancing the existing design, in an environmentally sensitive and appropriate manner, within the constraints of the limited fiscal resources, will be a major goal for the future.

Growing environmental concerns have lead to the evaluation of current golf course management techniques. Prominent environmentalists predict that half of the six thousand landfills currently in use are going to be closed by the
year 2000 (Perry, p. 30). Organic waste, such as grass clippings, leaves, and small branches which is in part generated on golf courses, takes up to twenty percent of landfill space. Because there are many alternatives for the disposal of organic waste, laws have been altered so that, in Ohio in 1993 landfills will no longer accept organic material. Since most of the organic materials from golf courses have been hauled to disposal sites for the last forty years, the evaluation of alternative organic material disposal routines is necessary.

Other management strategies that need to be evaluated are long range tree replacements, and, therefore, the analysis of the change of existing and proposed spatial characters.

**GOLF COURSE MANAGEMENT**

Management practices at The Ohio State Golf Course can be divided into two broad areas: Water management and land management. Each of these management areas has its own characteristics in terms of maintenance priority, environmental impact and spatial characteristics which can be evaluated by using three-dimensional modeling, CAD, and video image enhancement techniques.

**LAND MANAGEMENT**

The management and planting of shrubs and trees should enhance the golf game. The placement of trees and wooded areas during the design phase, or
when replacements become necessary, is based on whether trees in the pro-
posed locations will interfere with play and how they may enhance the chal-
lenge of shot making or the general aesthetic of the course. For the same reason
it is also common that trees and shrubs are chosen with branches that do
extend to the ground. Lost balls can be found more easily and mowers can get
closer to the trees and kill them under such elevated canopies. Often one of the
main goals in golf course management was to keep areas exceptional clean to
provide golfers with the manicured environment they have become used to
(Phelps, p.12). In earlier days, trees from the same species were planted over
large areas of the golf course, for instance, the large areas of ash on the north
edge of the property. Replacement often becomes necessary due to the aging
process or plant diseases and many courses lose their initial character because
trees are not replaced as they are removed. The lack of replacement plans and
knowledge of the exact number of trees on the course property and their spe-
cies makes the problem even worse.

The fifty year old Ohio State University Golf Courses have lost many of the
trees that existed in the original design, due to aging and diseases. The charac-
ter of the courses is in danger of being lost. While replacements of lost trees
takes place sporadically the new plantings seldom are near the place where old
trees were. The fear that trees could slow down play and effect the number of
golfers that can play the course in a given time is one reason, a possible increase in maintenance another. The impact of proposed tree replacement on spatial enclosures, or the effects on the playability on fairways could never be evaluated, because the generation of mathematically correct and photo realistic images have not been possible until recently. Computer generated images make it possible to judge alternative tree locations and sizes accurately and, therefore, have a great impact on the decision making process.

**Diseases**

Tree diseases have eliminated a large number of trees on The Ohio State University Golf Courses over the last two decades. It was common practice to plant trees of the same species together in certain areas on the courses. The ash tree for example has been a species that may soon disappear from the courses because of ash decline. The replacement of these trees is a major goal of the Greens Committee. The planting of trees has been very sporadic and because a replacement plan has not been worked out is often done without consideration of the initial design concept. A replacement plan should should be prepared which points out the location, the species and the year of planting of existing trees. It is important to plant trees in areas where it is known the spatial character will soon be altered due to disease or age loss. New trees take time to grow and develop to a size necessary to provide the areas of concern with a
similar character as when mature. It is, therefore, very important to replace trees early to bridge the years that it takes for young trees to mature. To avoid the loss of many trees in one area because of diseases many different species should be planted together. The replacement of the ash, for example, should take place with a variety more disease resistant species to ensure the success of the planting.

Aging process

The Ohio State University Golf Courses is about to lose a great number of trees because of aging processes. Since trees are planted shortly after the construction phase, many reach the end of their useful life at the same time. It is very important to think about early replacement in a organized fashion in order to retain or enhance the initial design concept. Early replacement is necessary to avoid long periods of time in which the initial spatial character created by mature tree is lost. The planting of new trees should take place at least five years before the old ones need to be taken out. An important part of design is an inventory specifying the age, species, condition and location of every tree on the courses. Unfortunately such an inventory does not exist. To keep the initial design idea for the courses is one major goal of the Greens Committee at The Ohio State University Golf Courses. The planting of young trees in about the same areas as the original ones helps to maintain existing spatial characters. Decisions about the location of new planting areas, the species, and the age of
the trees will have great impact on the appearance of the courses over time and should be made carefully.

Spatial character

The loss of many trees on the courses have resulted in the lack of spatial definition and character. Current replacement efforts are not keeping up with the pace at which trees are dying. The continuation of this process will ultimately result in a much altered spatial character on the courses. Trees should be placed to provide natural screening, and to create spatial enclosures, with the consideration for the playing of the game. Trees have been used as hazards, and therefore have been placed in certain locations to create more interesting game situations (Rulewich, p.18).

In order to maintain the original design concept and play situation, a spatial analysis should be conducted. The original design idea can be recreated and evaluated with plans or aerial photographs. The use of computer generated three-dimensional images during this process could be very helpful, because of the chance to actually evaluate design alternatives. Before and after images can be generated and used during the design phase as well as for client presentations. Clients can therefore take part in the decision making process and influence the ultimate solution.
The creation of spatial enclosures on the courses is not only important from an aesthetic standpoint but it also helps golfers to execute shots as intended. Spatial definition gives golfers a better feeling for different distances they have to face on each fairway. It also keeps the distraction from other players to a minimum.

The replacement of trees on the courses can be organized with the replacement plan and the list of the existing flora conditions described above. Again, the emphasis should be on early replacement plantings, with the best suitable species and in areas related to the initial course design solution. This procedure makes an undisturbed growth of shrubs and wild grasses possible, and will provide fauna with natural habitats (Steinegger, p. 18). The only point that could be made against such maintenance routines would be complaints of golfers about lost balls in these areas. The intended woodland management techniques are a step in the right direction. Ultimately, golfers, the maintenance budget of the courses, and the environment will benefit from the change resulting from these alternative woodland management techniques.

**Golf cart paths**

Golf carts are very destructive to turf on courses due to compaction of the soil. Golf cart paths were built originally to get the vehicles across the course but now have more fundamental roles in golf course design.
The Ohio State University Golf Course has incomplete paths systems which makes it necessary for golfers to drive over fairways. This practice increases maintenance costs. The management group needs to design a connecting cart path system. During the planning phase, consideration should be given to the effect on drainage, cost, maintenance, and interference with the play. The material currently used on the courses is asphalt, which has impact on the environment. Evaluation should be given to areas of standing water or infiltration basins, because the oil in asphalt breaks down over time. Other possible materials are mulch or interlocking polyethylene pavers through which grass can grow. These pavers have the advantage that the paths look natural and golf balls do not bounce as much while landing.

Cart paths should be an integral, deliberate part of each course design and utilized in ways which have positive environmental impact. They can be use as barriers or dividers between areas that need to be protected environmentally, and even be used as drainage channels (Falkner, p. 121).

Three dimensional modeling and video image enhancement capabilities of the computers could be very helpful during the planning phase for golf cart paths. Shaded surface models, showing before and after situations, can be used to evaluate the effectiveness of overall routing plans. Path alignment relative to the location of fairways, tees, and greens can be evaluated.
Video image enhancement can be used to evaluate the visual impact of proposed solutions. Different materials have different visual impacts. Different alternatives can be evaluated and, therefore, help to choose the best suitable material for paths. Possible interference with play can also be detected by analyzing images carefully and appropriate changes can then be made before construction.

WATER MANAGEMENT

Golf and water have been linked together since the game was first played. Lakes and ponds, often naturally existing on the site, are taken advantage of in various ways; fairways, greens, and tees are designed around them. Since the design of golf courses often creates many small water sheds, lakes and ponds can be used to solve engineering problems and are sources for irrigation water. These ponds also have aesthetic qualities which are, in case of the Ohio State University Golf Course, not taken enough advantage of, because little attention is given to the design of shorelines and adjacent edge treatments.

Lakes and ponds have a natural relationship to the game of golf including the attraction of human beings to water and to help solve possible on-site stormwater management problems in golf course design. Water is incorporated in design by placing water features so that they can be used as hazards. In areas where the permeability of the soil is low and no discharge point exists to handle the water, retention or detention structures can be
created to solve on-site drainage problems.

Shorelines/aesthetics

Either the water feature existed naturally on site, and used as it was in terms of appearance, or the design of lakes and ponds incorporated engineering aspects and placement criteria, but rarely all factors considered together. The edge treatment of lakes and ponds is especially important. Shorelines built out of appropriate natural materials will not have erosion problems and become natural habitats for animals. They also blend in with the rest of the environment. The shorelines of the lake and streams on The Ohio State University Golf Course need treatment and maintenance. Grasses and flowers that grow near or in water need to be introduced. To change lakes and ponds into natural habitats of flowers and grasses, special attention needs to be given to the bottom conditions of these water features. Shorelines leading into the water have to be shallow, so that plants can grow in the soil and still reach the water level. There also need to be areas with steep slopes and deep water for fish survival during the winter time and to maintain water quality.

The incorporation of lakes and ponds into maintenance routines on The Ohio State University Golf Courses is desirable. They are areas which need special attention and care. Water features that incorporate aesthetic design concepts enhance the overall appearance of the courses significantly.
Drainage

There is a problem of puddles in play related areas and their interference with the play of golf and maintenance routines on the course. Such problems often result when many miniature water sheds are created with no discharge points or gradients to shallow to guarantee the flow of water, typically due to poor design lay out. The existing soil condition also determines how much the water penetrates and has therefore direct impact on the build up of standing water. Solutions to these problems have been the installation of pipes and tiles which require large amounts of earth moving. Drain inlets, to capture excess water, are spread out all over the courses. The installation of pipes and tiles is expensive.

Natural elements can serve as discharge points, such as infiltration, wet or dry basins, lakes and ponds. It is also possible to create hazards out of wet areas that interfere with the play by introducing grass bunkers that serve as infiltration basins. These areas then have a function and golfers know that they are intended to be there. The solutions to drainage problems can be much more creatively incorporated into the game. There are many inexpensive alternatives to pipes and tiles that just have not been introduced as drainage problem solvers in golf course management and design.

Storm water management strategies can be incorporated in design solutions which are closely related to the game of golf.
Creative stormwater management solves possible flooding or drainage problems by treating the concerned areas as hazards in or on the side of fairways. The standard hazards used on the courses are sand bunkers, but there are many other creative solutions such as depressions or mounds with long grass or wildflowers (Kahler, p.132). The designer should always be careful about the placement of these hazards
AAA, so that the overall playability of the particular golf course is not effected. They are, in most cases, more cost effective than the use of pipes to route the water to existing discharge systems. Stormwater management decision making processes need to be incorporated into actual fairway maintenance. In order to determine which stormwater management solution is to be used, the designer has to consider playability aspects of the golf course as well as engineering aspects of each particular fairway design. To evaluate the impact of alternative locations, video image enhancement capabilities of the computer can be used.

The designer has to investigate the overall character of the course, so that the placement of hazards that solve possible stormwater management problems fit within the existing scheme. Existing topography is a major factor in the decision making process because earth moving must be held to a minimum.

The layout of the golf cart pathways has to be considered before placing hazards of any kind because the routing of paths should be as efficient as possible. The impact of golf cart paths on play situations or their visibility from
any given viewpoint can be studied by using 3D modeling software.

There are many different ways that hazards can be used to solve stormwater problems:

Vegetation/grass bunkers: These depressions can serve as dry basins. To make sure the vegetation has enough water available over a year, the use of irrigation should be a consideration. In case of flooding problems, water can be directed and held in these depressions and infiltrated into the soil, so the play on fairways is not effected.

Ponds: Water features can be used as a solution to flooding problems, with controlled in and outflows if desired. In case there is not enough inflow into the ponds, the water level can be sustained by using irrigation systems.

Roughs: Areas of rough formed into small depressions can help solve less severe drainage or flooding problems. Such areas have to be away from the usual play routes to avoid possible interference by standing water during play.

Swales: Careful grading can direct the flow of stormwater into desired areas away from the fairways. Piping the water underneath the fairways also avoids interference with play. In cases where the infiltration rate is not high enough, swales can be used to direct the water to wet, dry, or infiltration basins. Computer technology can be used to evaluate all of the above solutions in terms of their visual impact on the existing design, or possible interference with play.
In any design scenario, it is very critical to investigate the existing drainage channels in order to locate possible flood problems ahead of time. The location of fairways, greens, and bunkers can then be planned or appropriate modifications made in the location and size of drainage ways through regrading according to the storm water data. Stormwater data is used to determine the size, location, and necessary volume of structures catching the flooding water. The collection of data generally falls into two categories: first the data concerning the incoming water, and second the information regarding the soil, topography, and surface cover (SCS Hb., p.15).

Water: General information about the size of the contributing watershed, the existing drainage channels and discharge points can be found on USGS maps. The rainfall distribution and the intensity of design storms can be determined with the SCS Method. This method is used to calculate peak discharge at certain points inside the watershed. The peak discharge, in cubic feet per second, is needed to determine the size, volume, and location of possible discharge structures. If pipes are an option, the information is used to determine the required pipe size and slope.

Soil: The soil type and cover have a great impact on the amount of runoff during a rain storm. The soil type slope and surface cover need to be determined in order to find the amount of water infiltrating the soil. If the soil has a very small infiltration rate, the subsoil can possibly be changed in the
designated areas where water is supposed to infiltrate. The introduction of vegetation or natural grasses is dependent on the soil type and therefore needs to be investigated very carefully. Compared to areas with bare soil, areas that are covered with vegetation or natural grasses have advantages, because of the reduced runoff and increased infiltration of water into the soil. Runoff coefficients are calculated based on a combination of soil, land cover, and slope; they provide information about amounts of water infiltrating or running of the soil.

To avoid massive compaction of the soils, earth moving is to be held to the minimum possible. An investigation of the natural topography, its incorporation into the design, and therefore the use of natural drainage channels can help to avoid stormwater problems. Computer technology assists the visualization of the existing site topography through 3D surface models.

The existing conditions largely determine the possible stormwater problems and their solutions. Very careful evaluation and investigation in all aspects of design, especially stormwater management, can help prevent most problems. The creative use of stormwater management techniques can be the key to very interesting, attractive, and lasting designs without any flooding or drainage problems.

Many different approaches can be taken to solve stormwater problems. The incorporation of stormwater structures into hazards on the golf course design,
is a rather new and innovative technique.

Out of the vast number of structures to solve stormwater problems, three arrangements are applicable at The Ohio State University Golf Courses. Bunkers with vegetation and ponds are solutions which can be used as hazards and also solve drainage problems. Pipes route water to discharge points without interference with the play.

Pipes: In order to determine the diameter for the pipe, the peak discharge of the particular watershed needs to be calculated. In case of multiple inlets, the amount of incoming water at each inlet has to be calculated, which then adds up to the total peak discharge of the system. The length of the pipe and the location and elevation of the discharge point of the watershed has impact on the slope, and velocity of the pipe. It is necessary to design pipe systems in great detail to make sure the pipes are placed deep enough to avoid frost damage.

Grass bunkers: These hazards work as infiltration basins. The water that flows into these bunkers will stay in these depressions until it infiltrates into the soil. In dry periods during the summer months, these hazards can be watered as part of the irrigation system. In terms of the playability, grass bunkers can be treated like water hazards to avoid disturbance from players (Rulewich, p.16). The size of the hazard is determined by the peak in flow of water and the infiltration rate of the soil. The grass bunker is an enrichment for every golf course and is a very attractive and effective solution for on site stormwater
management problems. Construction costs are also minimal, if earth moving is kept to a minimum.

To make sure wild flowers and grasses can grow properly the soil type needs to be determined. If the soil is not suitable, the exchange with better growing mediums is possible. It is very critical to calculate inflow and infiltration rate correctly, because the health of the vegetation depends on the correct water level and moisture throughout the year.

Ponds: In storm water management ponds are used as holding structures for water and have in most cases a controlled outflow. The location of the water feature is largely determined by the course topography. The emergency discharge of these systems has to be designed in such way that the water is not flowing on fairways, greens, or tees, but directed to points on the golf courses where there is no interference with play. The soil type controls the infiltration of water and has therefore a great impact on the water level of the proposed pond. If the flow of water into the pond is not very high, a soil with minimal infiltration rates is desirable. If larger amounts of water are flowing into the water feature, a soil with a higher infiltration rate would be more suitable. The careful planning of these factors can limit the need for the emergency discharge system. The volume needed to store in coming water is influenced by the peak discharge rate of the contributing watershed at any particular time.

To create a suitable solution to on site flooding and drainage
problems special care needs to be given to treatment of the edges of the water bodies. Many species of flowers and grasses grow in these areas and provide a welcome alternative to water edges that are often boring. Because the location of these water features is largely influenced by the topography, the designer has to give special thoughts as to how the placement of a pond alters the playability of fairways.

Stormwater management and all other engineering aspects in design are often treated as a separate entity. The incorporation of engineering aspects does not have to be a limitation to creativity in course management and can be an enrichment.

The scenarios discussed above are good examples of how functional and engineering aspects can result in attractive designs. The most engaging solutions are the grass bunkers and the ponds. Both hazards may be used to solve drainage problems. It would be desirable if designers were more aware of the creative problem solving tools and would use them accordingly. The incorporation of stormwater management tools in the design process and management programs can help prevent most of the flooding and drainage problems at The Ohio State University Golf Courses and result in attractive and functional solutions.

The impact of stormwater management alternatives can be studied effectively with 3D modeling and video image enhancement techniques.
The evaluation of these alternatives in the third dimension will lead to the best possible solution.

**LONG RANGE MANAGEMENT AND ENHANCEMENT PROGRAM**

The Ohio State University Golf Course management groups face the challenge of modifying current maintenance routines because of changing laws and a more environmentally conscious society. Current practices do not meet the future standards set by law. New management and maintenance alternatives need to be explored. Three dimensional modeling and image enhancement capabilities of the computer are very valuable during this process. Computers allow users to explore design alternatives, perform spatial character analysis, and because of their ability to generate realistic video images they offer advantages during client presentations.

The combination of state of the art golf course management and maintenance practices, and computer modeling and enhancement technologies will lead to the development of prototypical long range maintenance and management programs for the courses with emphasis on environmental consciousness.

**SITE/PROBLEM ANALYSIS**

Problem analysis is a vital part of developing alternative management and maintenance routines. During the analysis phase, areas for improvements are pointed out and current practices evaluated in terms of their sufficiency. Many golf courses around the nation face similar challenges.
For example the recreation of original design ideas, drainage and stormwater management problems, the improvement of play related structures, aesthetics, and the need to introduce environmentally sound maintenance routines are all areas that should be addressed. The courses have to evaluate current maintenance and management routines and determine whether changes have to be made. After the analysis phase is completed, a priority list must be created. Priority lists should state problems and assign a rank to each item. Once a priority is assigned, projected problem solving dates can be determined. It is important to point out that every golf course has unique characteristics and needs special attention in certain areas. Designers and management groups should pay tribute to the uniqueness of courses by treating each design as a separate entity.

The Ohio State University Golf Courses, in particular, currently put an emphasis on the improvement of greens, tees, sand traps, and cart paths. The management group of the courses also determines the need for introducing environmentally sound maintenance routines. Topics needing to be addressed are the replacement of trees, spatial characters, water management, land management, and aesthetics.

To replace trees in an organized fashion, a long range tree replacement plan has been drawn up. The plan points out the areas, species, and day of planting. It is very important for the courses to gather information regarding
the existing condition, species, age, and life expectancy of each tree, to ensure early replacement.

The analysis of spatial characters is of major importance for the recreation and maintenance of the original design idea. Due to the loss of a large number of trees, the courses are now relatively open and lacking in spatial character. The use of 3D modeling and image enhancement techniques of the computer are essential to evaluate design alternatives. The analysis of spatial characters goes hand in hand with the replacement of trees and the determination of areas that need special attention in that regard.

Water management, including the treatment of drainage problems, should be part of maintenance and management plans. Puddles and wet areas often interfere with play. Water management offers various creative solutions to these problems, such as, grass bunkers used as infiltration basins, or cart paths used as drainage channels. The introduction of new water features, their size and water quality should also be evaluated.

Currently much time is spent on the maintenance of woodlands on the courses. Maintenance time can be drastically reduced, by keeping these areas in a more natural state. The environment will benefit, because natural habitats for wildlife have been created.

More attention should be given to aesthetics on the courses. Areas that are treated in a special fashion, enjoy special attention of golfers.
These areas could be highlights on the courses. During the spatial character analysis, areas needing attention can be pointed out. Wild flowers or natural grasses could be introduced and serve as focal points. This not only has impact on the natural environment, but also helps golfers to plan their shots more accurately because spaces can be perceived with more depth.

Wildflowers should also be introduced in some out of play areas to reduce areas that need to be mowed. These areas almost need no attention once established. The location of wildflower areas is determined by their interference with play and suitable growing environments. It would also be feasible to mow the grass in the remaining rough areas less frequently. These techniques lead to a reduction in generated organic waste and maintenance time. On site composting would offer a valuable alternative to grass clippings and leaf disposal, and could be easily incorporated in current maintenance techniques.

SITE SPECIFIC SOLUTIONS

Once the problem analysis phase is completed, the created management plan and priority list should be used to determine future maintenance routines. Golf courses across the nation use different maintenance routines because of the unique characteristics determining different levels of priority. Some courses might need to put emphasis on the replacement of trees, others on mowing techniques or organic waste disposal. To guarantee the proposed changes in management and maintenance routines fit the unique characteristics of each
area on any golf course in the nation, the efficient use of the data gathered during the problem analysis phase is very important. The use of alternative maintenance routines often depend on how well they can be incorporated in the current management processes in use on golf courses. The evaluation of all routines in use must be completed before new techniques can be efficiently introduced. The close cooperation of designers and management groups is essential for the success of the proposed changes in maintenance routines.
CHAPTER III
COMPUTER TECHNOLOGY

HARDWARE

Powerful computer work stations capable of interactive three-dimensional modeling and integrated technical calculations are needed to generate accurate representations of three dimensional environments.

Personal computer work stations with at least 386-25 Mhz math processors, 5 or more megabytes of random access memory (RAM), a VGA-monitor, and 60 megabytes of disk space provide the designer with speed and storage space for files to perform three-dimensional modeling for natural environments. A laser printer or plotter is desirable to print or plot computer generated plans, however files can also be taken to print shops. For image processing a TARGA board, an analog or multi-synch monitor, a video camera or color scanner, and a video cassette player (VCR) need to be added to allow development of desired alterations on existing real world images.

3D MODELING SOFTWARE

Many two dimensional CAD software packages are on the market but fewer are available for three dimensional design. For this project AutoCad (ACAD), a full featured 3D CAD package, in conjunction
with DCA Engineering software was used to create a 3D model of the existing conditions of the Ohio State Golf Course.

ACAD/DCA

Computer aided drafting and design was first introduced in 1964, however, it was not widely used until 1982, when CAD systems such as ACAD became available on personal computers. One of the advantages of computer drafting is the ease with which changes can be made in drawings. The drawings created with computer technology are also more accurate than the ones created with the traditional hand-drafting method. The designer can make use of built-in measuring capabilities and automatic dimensioning features. AutoCad drawings are mathematical databases. The position of each object in a drawing is stored as an x,y coordinate in a database which is translated into an image on the screen. These coordinates are numbers allowing the computer to position points, which are components of objects on the screen, relative to each other in correct locations. To obtain three dimensional objects, two dimensional lines drawn need to be extruded into space. In the resulting drawing data base, each object is now represented by x,y,z coordinates, where x and y represent north/south coordinates of locations and z represents elevations.

AutoCad is a generated drawing package which can be used for various applications, but is especially suited to architectural and engineering purposes. It is not difficult to create two dimensional plan drawings or three dimensional
objects placed on flat surfaces. Landscape Architecture deals, for the most part, with existing topographies. Three-dimensional objects are created using coordinates with z values, representing the elevations of a point in space. Z represents values corresponding to existing topographies assigning elevations to points in space in drawing data bases. To modify a drawing package to meet the specific needs of the Landscape Architect, the software needs to be customized.

DCA is a software package for use “inside” AutoCad which engineers and Landscape Architects can use for their specific needs. The DCA Earthworks and Digital Terrain Modeling (DTM) modules can be used to create three-dimensional representations of outdoor environments. Existing topographies are represented on the screen by three-dimensional grids. Wire frame drawings of any given structure can be placed onto the grids representing existing topographies. The designer can manipulate these grids and generate representations of proposed surfaces. These modules can also create cross sections and profiles through the three-dimensional model. If desired, the DCA modules can be used to calculate cut and fill, helping the designer to evaluate the bearing of proposed changes. The biggest advantage of this customized software package is that objects can be placed easily in space and be evaluated under the predefined design guidelines. The created three-dimensional grids, which are generated from x,y,z files or digitized contour lines, can be changed easily,
making it convenient for the designer to experience created design solutions in the third dimension.

The introduction of computer technology to landscape architecture influences the development of the profession. Before three dimensional drafting capabilities of the computer where used, only very few people could visualize the impact of proposed designs. Sketches and perspectives, which are artistic representations of proposed objects, were prepared often after major design decisions had been made. Through the use of computer technology it is now possible to quickly create mathematically correct images. The designer can use these images during the design process to evaluate the decisions made and make changes whenever necessary in order to achieve the best possible solution. The three dimensional drafting capabilities of the computer are also very helpful for presenting design solutions to the client. Even people that have little experience in reading two dimensional plans have no difficulty in perceiving the way prospective solutions work in the third dimension. It is possible to get valuable feedback from various persons which helps the designer to find the best possible use of various proposals.

**DIGITAL TERRAIN MODELING**

To obtain a three dimensional computer representation of topography, one must convert the information given on plans into digital format data bases. In some cases, digital data bases are provided by the city or state agencies where
the project is located, but this is still rather an exception than a rule. The most common way to convert data into digital format is to trace contours lines of a plan on a digitizing tablet. The computer will assign to every point digitized a set of \(x,y\) coordinates representing its location in space a \(z\) coordinate representing the points elevation can also be entered at this time. The computer creates \(x,y,z\) files, where the \(x\) value represents a northing, the \(y\) value a easting, and the \(Z\) value the elevation. Another possibility is to create the \(x,y,z\) file without digitizing by laying a grid over the plan. Each corner is given an northing, easting, and elevation. These numbers are then typed into an Ascii or text file which is read by the computer software. The point information, regardless how it is captured is the base for the creation of three dimensional representations of topographies.

\[
\begin{array}{cccc}
3000 & 3001 & 3002 & 3003 \\
840.30 & 841.30 & 841.40 & 840.30 \\
\end{array}
\]

\[
\begin{array}{cccc}
2979 & 2980 & 2981 & 2982 \\
841.00 & 840.30 & 840.20 & 839.90 \\
\end{array}
\]

\text{figure III, 1 points}
Point information files are then converted into a triangulated irregular network (TIN), which describes the represented surface by coordinate triplets. These coordinate triplets are connected by lines that form the boundary of a triangle. It is now possible to determine the elevation of any point within the triangle by linear interpolation between the elevations of the corners of each triangle. The computer can perform the mathematical operations needed very quickly, making it a very powerful tool for the generation of three-dimensional models.

TIN models guarantee that the elevations representing the model are the same as the elevation used to create the model, which is achieved by the great accuracy of the linear interpolation technique and the shape of the triangles. Still, it is very important to understand that DTM can only be as accurate as the data used to create them. The designer must assure that the digitized or calculated point data is correct, so that the model adequately represents the desired surface.

TIN models are used to calculate elevations of any given point within a specified area, but they do not represent a three-dimensional surface (figure III, 2 page 41). In order to view surfaces three dimensionally, grids have to be generated. The computer checks the TIN model data and assigns elevations to the corner points of each grid cell, which makes a representation of the surface visible (figure III, 3 page 41).
figure III, 2 triangulated network

figure III, 3 three-dimensional grid
Besides the three dimensional grid, a series of contour lines can also be generated. Once the TIN is created, digital terrain modeling is then only a matter of retrieving information. In most cases the existing topography needs to be manipulated to suit possible design solutions. In order to do so, existing point files have to be changed. With the point data for proposed conditions, a new TIN model is created. The three dimensional grid of the proposed TIN then represents the new surface model. The impact of grading on the existing grounds can be evaluated and easily changed if desired.

Digital terrain modeling is simple once the designer has an understanding of the conceptual basis. Model surfaces can easily be modified and the impact of design solutions evaluated.

So far the discussion has been limited to the digital terrain model; what about the design elements that need to be placed on the surface model? Once the grading process in the desired areas is completed, the outline of the proposed structures are to be projected on to the terrain model (figures III, 4-9 p. 43-45). The design can now be viewed as a wire frame model in the third dimension. Still, wire frame images might be hard to interpret by clients. To make models more realistic, wire frame drawings can be converted into solid objects that contain a surface. This process is called shading.
figure III, 4 plan with play related structures

figure III, 5 grid with play related structures
figure III, 6 wireframe and plan

figure III, 7 grid and existing lake
figure III, 8 wireframe

figure III, 9 perspective view
AUTO SHADE

Autoshade™ is a rendering program that converts AutoCad’s three
dimensional wire frame images into surface models. AutoShade is used after
the AutoCad drawing is created. AutoCad drawings have to have specific
formats to generate surfaces. AutoShade will be able to read 3D faces, circles,
solids, traces, doughnuts, and wide polylines. Wire frame images are often
hard to read and understand because of the lack of representative attributes.
Shaded surface models are much more realistic and can often times be used to
find inaccuracies in three dimensional wire frame drawings that otherwise
would be difficult to detect. A shaded image allows one to visualize the relative
placement of objects much more clearly and easily. These shaded images can be
used to explore possible design solutions, because the proposed objects can be
viewed from many different angles (figures III,10-17 pages 47-50)

The first steps in creating rendered images take place while working in Au-
toCad. The colors used in the Cad program determine the color in the render-
ing. “Cameras” are placed in the drawing to specify viewpoints from where the
proposed objects are being observed. With this information a filmroll can be
created containing three dimensional objects, lights and cameras that Au-
toShade will use to create renderings. The user then exits AutoCad and enters
AutoShade.

Upon entering AutoShade, the filmroll file created in the Cad program
figure III, 10 before gray 11

figure III, 11 after gray 11
figure III, 12 before scarlet 12

figure III, 13 after scarlet 12
figure III, 14 before 14 gray

figure III, 15 after gray 14
needs to be loaded. A new internal database of the entities of the drawing is then created. It is now possible to display the drawing from any desired viewpoint and shade it according to the position and the intensities of the light sources selected. Very spectacular images can be generated by placing the cameras on the eye level of an potential viewer. By creating a sequence of scenes, the illusion of actually walking through the designed space can be conceived.

AutoShade gives the designer and the client the chance to view proposed objects in a realistic fashion. It is an important tool not only during the design process, solutions can be viewed instantly, but also for client presentations. The often innocent client can visualize design alternatives in a realistic and mathematically correct fashion a way that has never been possible before.

**VIDEO IMAGE PROCESSING**

The use of video image processing techniques takes the Landscape Architect one step further towards the creation of real life images. The representation of proposed design solutions can be so realistic, that it would be impossible to tell, which image is real and which one is not. Image processing is an outgrowth of the movie and advertising industries, that borrowed these techniques from military surveillance and space exploration. Image processing got introduced to Landscape Architecture through companies that tried to broaden their services for various clients, or to gain marketing advantages on a highly
competitive market. Illustrated alternatives are presented as life like images of design solutions, so that even very complex problems can easily be understood. During the site analysis phase, the impact of design solutions on wildlife, vegetation, or spatial character can be studied. The generated computer images can represent the project surroundings realistically, while enabling the designer to experiment with alternative preservation, restoration, or replacement options. Image processing techniques also allow the client, or the public, to participate in the design development.

The image source for most users are either live videos from a video camera or scanned pictures from slides or hard copy photographs. To convert composite video inputs into digital images for display by the computer, the designer needs a converter/digitizer. An existing scene is captured on the screen from a live or taped video or photograph and then edited using painting TIPS software.

Paint and editing programs allow the user to alter portions of desired images. Cut and paste functions make it possible to move objects to new locations. Objects can be captured direct from the image or from files that provide various kinds of site elements.

For video tape output, an encoder and digital-to-analog converter is needed. Prints can be made of the screen through a dot matrix printer, or color slides can be photographed for presentation purposes.
The use of AutoCad wire frame drawings, that show the proposed changes to scale and with real world coordinates, assure that proposed images show design solutions accurately. Shading techniques used in paint and editing programs then allow the designer to create the desired surfaces. These programs have a wide range of editing capabilities. Various kinds of trees can be inserted into an image that show proposed solutions. Textures, and site elements can be taken from computer files, out of magazines or catalogues and inserted on to images, to make the presentation of proposed design solutions as realistic as possible figures III,18-23 pages 54-56).

SOFTWARE PROBLEMS

The process of creating real world three dimensional computer models is long and tedious, because the technology is not aimed to deal with the shapes of natural environments. The use of computers for digital terrain modeling is helpful but touches its limits because of the size of the projects landscape architects usually have to deal with, which leads to disc storage and memory insufficiencies.

Triangulated irregular networks (TIN's) are used to calculate three dimensional grids, representing topographies. The maximum number of points from which a TIN can be generated, using DCA software, can not exceed 30,000. It takes for example 8560 points to generate a TIN model for the Ohio State Golf Courses, an area approximately 420 acres in size.
figure III, 18 before rough area

figure III, 19 after rough area
The point files, files for the triangulated network, and the three dimensional grid are not stored as part of the drawing, but in a separate directory on the hard disc with different project identifications. The data stored can be accessed from any drawing file, because the program is set up, to look for the desired data in specific directories. This procedure keep the size of drawing files manageable and regeneration time to a minimum.

Compared to the creation of TIN models, which can cover large areas, the generation of three dimensional grids is limited to the transformation 4500 points. Three dimensional grids created from larger point files are often faulty and lead consequently to problems when lines are to projected onto the grids surface. To generate TIN models in portions of bigger sites is not feasible because of calculation errors at the edges, that lead to the difficulty, that three dimensional grids do not connect in the third dimension. To handle that problem, two separate TIN models need to be generated with different project identifications. The data can be accessed from the same drawing file and assures, that the grid generated connect at the edges. Each TIN serves then as the base the three dimensional grids that need to be created. This procedure limits the number of grid points calculated. Both grids from the two identical TIN models are visible in the drawing and can each be manipulated by assigning the corresponding project identification.

Due to the size of many projects, manipulating three dimensional grids can
be very time consuming. It is expedient to manipulate portions of the site, which can then be inserted into separate drawings, using the same project identifications of the TIN of the original drawing file. The drawing on which the changes have been made can then be reinserted back into the original file.

Besides few obstacles, the DCA software program produces accurate representations of natural environments quickly and is very user friendly. It is often necessary to make a lot of changes to three dimensional surface models, before the results are satisfactory. The DCA digital terrain modeling module makes design in the third dimension easy, and time effective.

**COMPUTER USE**

The exploration of three dimensional spaces has always been of interest in landscape architectural design. This is especially important in golf course design and management. During the design development phase, in order to visualize the impact of proposed design alternatives, has been common practice to draw sketches to explore 3D spaces (Carpenter, p.1). This practice, however, is not very effective, because the renderings are rarely to scale and often are created for presentation purposes after decisions have already been made. The computer gives the designer the ability to create mathematically correct representations of outdoor spaces. This has major advantages for explorations of three dimensional spaces. It is possible to judge the impact of proposed
solutions and explore design alternatives. Another advantage of computer generated perspective renderings is their helpfulness during client presentations (Danahy, p.65). Even inexperienced viewers can explore design alternatives realistically and judge the final impact. This is of major importance because one tends not to make decisions without knowing exactly what the impact of the proposed design solution might be.

3D MODELING

Many management groups face the challenge of deciding on design alternatives without being able to picture what the impact might have on proposed solutions of existing designs. Artistic renderings which are often used to represent three-dimensional environments are insufficient, because they are rarely drawn to scale. Computer technology capable of three-dimensional modeling makes the creation of realistic representations of spaces possible. These computer generated drawings show objects in the mathematically correct location and can be viewed from any angle. This is especially important for spatial character analysis and impact studies. The drawings created in ACAD are wire-frame drawings that are hard to interpret. To create more realistic images that and, therefore, make the evaluation of design solutions easier, the ACAD drawing is transformed into shaded surface models. Shaded models are able to exhibit design alternatives effectively, because even the unexperienced viewer can get a sense of the create space. This section is very important
during decision making processes, because design alternatives can be evaluated effectively. Because of the chance to view objects from birds eye perspectives, as well as eye level perspectives shaded surface models can be used very conclusively to study any given area. Therefore it is possible to examine the overall impact of proposed solutions by choosing views from up in the air. Eye level views would give the user a feeling of the created space or spatial enclosures. Before and after models can be created and used during the decision making process to evaluate alternatives. Computer generated shaded surface models and their use during the design phase and decision making process guarantee that the best possible alternative is chosen.

VIDEO IMAGE PROCESSING

Video image processing is the ultimate solution in evaluating design solutions realistically. Images of existing conditions can be altered, so that they reflect proposed designs. In order to be able to render realistic video images to scale, a wireframe drawing created in ACAD is overlaid on top of the image showing the existing conditions. Concerned areas can now be rendered. The finished image will show the proposed solution in a realistic fashion. The creation of before and after images is very helpful to evaluate visual impact and spatial characters on areas determined during the problem analysis phase.

Video image processing allows the designer to judge and choose design and maintenance alternatives effectively. The impact of proposed
water features, cart paths, tree plantings, and wildflower areas can be studied in a realistic way. Video images encourage clients to participate during decision making processes, because of the chance to evaluate and not just build design alternatives in a realistic manner. Computer technology is an important tool which should be used extensively, especially in natural environments, because of the ability to generate mathematically correct realistic images. The use of video image enhancement adds a new dimension to golf course maintenance and management.

Golf courses should incorporate computer modeling and video image enhancement techniques in their management and maintenance routines. Computers are helpful tools for detecting problem areas on courses and presenting possible solutions to management groups. They should be vital part of the design and decision making process. Today's maintenance and management programs must emphasize long range plans, where possible problems are detected early, and possible solutions are planned in advance. Computer technology would force superintendents and management groups to think about alternative maintenance strategies as early as possible, because of the ease with which decision can be made based on realistic images.

**SPATIAL CHARACTER ANALYSIS**

Older courses often face the problem of the loss of initial design ideas due to the inefficient replacement of trees, or erosion processes. At The Ohio State
University Golf Courses, spatial characteristics of the original design concept are no longer available. The greens committee is unable to make design decisions regarding tree replacements, cart paths, wildflower areas, or water features because there is an inability to explore spaces presented two-dimensionally in the third dimension.

Computer generated images make the exploration of three-dimensional spaces possible. During the design phase, different spatial enclosures can be analyzed. Tree replacements have great impact on spatial enclosures. Views change and influence the playability of holes. The restorations of original design solutions are difficult, because plans are often not traceable. Areal photographs can provide the designer with the information needed. Trees can be located and areas which originally had different uses can be detected. Topographic maps most often exist and can be converted into digital format. After the data from both sources is transferred into one drawing, three dimensional models for any given moment in time can be created and analyzed. These mathematically correct three-dimensional models can be converted into shaded surface models or video images. The designer now can explore the spatial enclosures and characters concerned areas of courses. Decisions can be made whether past solutions are still suitable or if entirely new alternatives should be explored. Alternatives can be evaluated in terms of their suitability for present conditions.
DECISION MAKING PROCESS

Computer generated images are an important tool in the decision making process; they are not only valuable for the designer during the design development phase, but also during presentations. Clients can analyze different design solutions in a realistic fashion. This has never been possible before because of the accuracy with which images are created has been unavailable. The clients get the feel for the space and the intended solutions. Knowing what exact impact decisions are going to have in the future will definitely speed up the decision making process. One does not have to rely on artistic representations of spaces anymore, but instead, one can trust the computer images generated. Since the computer has not yet been widely used, clients seem to be overwhelmed by the results. It is important to point out that images are only as accurate as the data with which they are generated. Designers now have the questionable power to move objects to suit their design solutions while still presenting them as accurate representations of outdoor environments.

Computer technology is very helpful for the explorations of spatial characters on golf courses and during the decision making process. Clients and user groups should be made aware of the power of these systems to generate images that are slightly changed compared to real world environments. These images can be presented accurately without anybody being able to detect the difference.
Clients and user groups should be critical and take these images for what they are, tools to represent three-dimensional spaces and to ease decision making processes.
CHAPTER IV
MAINTENANCE Routines

HISTORY OF GOLF COURSE MAINTENANCE

Golf course maintenance has gone through many changes during the last eighty years. In the early stages, turf grass was cultivated using natural substances. Grass clippings were composted and used as top dressing for greens and tees.

The use of natural plant extracts to improve turf quality was very successful but it also encouraged the growth of weeds (Mascaro, p.28).

From 1920 to 1930 the belief was that more acid soils would grow fewer weeds. The growth of weeds decreased on soil with pH values of three to four, but the turf grasses also grew poorly because of their intolerance towards acidic soils. During the 1930’s, the pH value was adjusted to neutral with lime. The heavy grass grown in neutral soils did more to prevent weeds than a thin stand on acid soils.

Between 1940 and 1950, it was common practice not to use topdressing because of the shortage of manpower for maintaining the golf courses caused by the War. During the first five years of this practice, no problems were experienced, but later the greens became soft. Thatch and mat were beginning to
stress greens and fairways. This era stimulated research and the results still influence the maintenance and management practices, today (Mascaro, p.29).

In the 1950's, two management practices were proven to be ineffective. First, topdressing was used over thick layers of thatch. Even today we can still find greens with many layers of thatch and topdressing having an effect on the turf grass quality. Second, topdressing was a mixture of components rather than homogeneous compost, which made the quick separation by water possible. At this time, the true art of composting was already lost for the golf course industry as a result of research in chemical disease and growth control.

In the 1970's and 1980's, pure sand was used as topdressing, making the greens very hard. Sand was used because it was inexpensive and drained effectively. Later, because of recommendations of the USGA Green Section, the sand was modified with a small amount of soil and organic matter to increase bacterial action and consequently the turf quality.

Some of the described techniques still influence maintenance routines practiced today. Golfers are now use to manicured and well maintained courses. Today's golf courses provide golfers with the environment they demand, but the courses lack challenging play on fairways. Finding lost balls in roughs is deemed more important than having flowers or shrubs on the course for aesthetic impact. To keep golf courses manicured is a very expensive practice. Many hours are spent on the greens, roughs and fairways, and also the
disposal of leaves and grass clippings. Manicured courses, in addition, require tremendous amounts of fertilizer, pesticides and water. (Voykin, p.11) Golfers, on the one hand, are concerned about high quality lawns, and golf course management on the other hand, is concerned about the number of players that can play the course in a given period of time. One factor limiting the number of players that can play the course in a given period of time is the total number of hazards. If trees, roughs, areas with wild flowers, and shrubs are kept to a minimum, players can reach the greens without being penalized for badly executed shots. This offers a definite time advantage.

A closer look at the development of golf course maintenance and the attitudes of golfers and superintendents towards maintenance reveals that golf has lost its link to nature. The environment in which the game is played is not appreciated. Extensive earth moving and the loss of existing vegetation when courses are built is also an indication for shifted priorities. Planning criteria should be aimed at preservation and cultivation of natural areas within the golf course.

PLAY RELATED OPEN LAND MAINTENANCE

Today the game of golf is played on manicured parks, with no resemblance to the rural environments as in England and Scotland, when started. For the last 20 years courses in America have been maintained in a way in which golfers can go for distance without concern for accuracy.
Since roughs and fairways are kept short, and courses kept open, players do not get penalized for badly executed shots (Voykin, p14).

Explanations for manicured golf courses are not hard to find. On the one hand, the attitude towards golf and maintenance processes are aimed to support a fast game, and secondly, the varieties of grass species being used are selected for the manicured look. Most of the grass varieties on today's golf courses have been developed recently, with 70 percent in the last 25 years and 30 percent in the last 5 years. These grass varieties require great amounts of fertilizer and pesticides to be kept in playable condition (Voykin, p.11).

Another reason for high maintenance effort on golf courses is that natural materials for topdressing and fertilizer are used infrequently. Organic materials support root systems and growing patterns, and cut the need for fertilizers considerably. Over fertilization and irrigation are reasons for shorter periods between mowing operations.

Currently, on The Ohio State University Golf Courses conventional maintenance routines are being used. The courses are well maintained and offer golfers considerable penalty free play. Grass is kept reasonably short. Tees, greens, and fairway bunkers are mowed as part of the fairways. This procedure alone significantly increases the amount of organic materials that need to be disposed of (Huffin, p.29). Grass clippings are being disposed by being spread thinly in areas considered out of play. Excessive clippings and leaves are
picked up by The Ohio State University, which uses the organic materials as fertilizer on their agricultural fields.

Golfers have resisted changes to a more reasonable level of maintenance because they are used to manicured courses and penalty free play. Managers of the courses usually want to move as many players over the courses daily as possible, a way to increase revenues. The growth of fairway turf all over the golf courses was the ultimate solution and resulted in unhealthy grass. These attitudes have carried maintenance costs to an extreme.

The game needs well maintained courses, but should be at the same time, challenging, beautiful, and fun to play. Golf should be a game of skill as well as a game of competition (Phelps, p.12). The improvement of environmentally sound practices goes hand in hand with the development of more strategic play. The courses are landscapes of living plants. Ingredients besides turf are shrubs, perennials, annuals, ground covers, and trees. Multiple landing areas separated by devasting roughs and hazards could give fairways a more aesthetic and strategic appeal.

The created natural areas on well maintained courses results in the reduction of areas that need high priority maintenance. The amount of generated grass clippings will be reduced significantly, the play will be more challenging and the environment will benefit (White, p.3).
MOWING TECHNIQUES

Mowing techniques used on today's golf courses are based on the simple principle: to serve the golfer who is "spoiled" to the point of always having to have the ball in a playable lie (White, p.1). Generally grass is mowed too frequently and kept too short. Golfers use different areas of golf courses more or less frequently, therefore, some areas have higher mowing priorities than others: greens have the highest importance, and roughs require the least amount of maintenance (White,p.2).

Greens have to withstand high amounts of concentrated wear and need increased maintenance. They are mowed daily and the grass is kept very short. The playability of greens is very important. They can be too fast or too slow, depending on grass type and the use of topdressing. Fertilizer and irrigation techniques are also essential to good root development and thickness of the grass. The size of a green has impact on the wear and the amount of clippings produced. Greens that are too small have excessive wear. With greens that are large and require more maintenance time, and higher rates of fertilizer and irrigation.

Fairways are mowed, in most cases, three times a week. The lack of strategic or aesthetic appeal is evident on many courses. Bunkers, tees, and greens are mowed as part of the fairways and not as part of the roughs, which significantly increases the amount of clippings collected.
Roughs are areas distinguished by grass that is kept longer and more natural, are almost unnoticeable in comparison to golf courses in England and Scotland (Phelps, p.12). Roughs are mowed too short and too frequently, and produce a great amount of grass clippings. Roughs with grass that is kept longer reduces mowing time and the amount of clippings that need to be disposed.

Tees like greens are areas that are subject to great wear. They are mowed, fertilized and irrigated too frequently. Excessive fertilization and irrigation are required because of heavy, concentrated use. The size is important because of their heavy use; tees which are too small obviously wear out easier than large tees.

Certain areas on The Ohio State University Golf Courses need different amounts of maintenance. These areas need to be detected and a maintenance priority assigned as a first step towards efficient and effective mowing techniques. The emphasis must focus on the reduction of the areas that need to be mowed. The reduction of mowed areas result in time advantages and ultimately in a concentration of maintenance in high priority areas (White, p.1). These areas are bunkers and greens, followed by tees and fairways. Roughs are maintained but have the lowest priority in terms of maintenance.

Greens are the most important areas on the golf course because the average
golfer takes half his strokes on the green (White, p.2). Maintenance cost are in
direct proportion to the size of the areas. Smaller sized greens are not
necessarily the solution for reduced maintenance cost because of the heavy traf-
fic in proportion to the size results in greater wear on the turf. The results
become higher maintenance costs due to the increased use of fertilizer and irri-
gation. Finding the optimum size for greens is often at the hands of experi-
enced superintendents who make these decisions according to specific
conditions of each hole.

Root development and, therefore, the health condition of turf, is directly
related to the cutting height, nitrogen level, cutting frequency, and water man-
agement. Since greens tend to be over fertilized and over irrigated, the careful
use of these materials is very important. A quality turf has not only an impact
on the playability of greens, fast against slow, but also reduces maintenance to
a reasonable level.

The second area of priority on the courses should be the tees. For tees, size
considerations are as important as for greens. Tees that are too large result in
longer mowing time, while tees that are too small increase wear and
maintenance needs. The larger size tee has better turf regrowth and does not
need as much fertilizer and reseeding. The placement of trees next to tees also
help the grass quality because they provide shade. The other advantage of trees
next to tees is the increase in aesthetic character.
Bunkers, should be third on the priority list, because they receive a good amount of play, and are expensive to maintain. However, they add to the aesthetic quality of golf courses. The number of these hazards should not exceed fifty or sixty on an 18 hole golf course (Finger, p.19). The reduction of the number of sand bunkers on the courses results in a decrease in mowing time. In order to provide golfers with challenging play, a reduction in number of sand traps, can be offset by the installation of grass bunkers. Grass bunkers require less maintenance, have aesthetic values, and challenge the player. Even so, the number of sand traps on The Ohio State University Golf Courses is in the recommended range, fifty-five for each course.

If a reduction in the total number of sand traps is not an option, consideration can also be given to the size of sand bunkers. The size of hazards are in direct relationship to the maintenance cost. Reduction in size results in reduction of cost (Finger, p.21). Mowing time around the edges of sand bunkers can also be reduced by keeping the grass in these areas longer. This practice would add to the aesthetic value of sand traps and reduce maintenance costs. The environment would also benefit because of the reduction of organic material that needs to be disposed of.

Fairways should be maintained with less priority than greens, tees, and bunkers. Common practice is however, to keep the grass on fairways short, resulting in high mowing frequencies and large amounts of grass clippings.
needing to be disposed. Another factor is the increase in fertilizer and necessary irrigation. To reduce the size of fairways on the courses must be a goal for the future. It would be desirable to create multiple landing areas separated by roughs which require even less maintenance. The reduction of fairway areas would challenge the player and add to the beauty of the courses while decreasing maintenance efforts.

Rough areas are almost not detectable on both courses. Current practice is to spread out the grass clippings in the so called out of play areas. The amount of time spent mowing the roughs almost equals the time spent on fairways. This amount of time indicates that there is not any distinction between the maintenance routines for roughs or fairways. Roughs should be areas, with grass kept significantly longer than on fairways. The mowing frequency should also be reduced to a minimum.

The Ohio State University Golf Courses maintenance program should put emphasis on the condition of the playing surface, instead of the expense of appearance. Even so, maintenance routines currently in use are quite successful, but many of the described alternative maintenance routines should be considered. Selective types of maintenance routines should be introduced immediately. Greens, tees, and bunkers are maintained with high priority on the courses, but consideration needs to be given to the size of each individual area and the treatment of their surrounding edges.
The maintenance of low priority areas can be improved by reducing the areas of fairways through increasing the roughs. The introduction of wild flowers and natural grasses would support the decrease of maintenance in concerned areas.

Three-dimensional modeling and video image enhancement techniques of the computer can be used for the exploration of alternative mowing techniques effectively. It is important to address these different alternatives in order to obey changing laws and environmental consciousness.

**ORGANIC MATERIAL DISPOSAL**

Many different techniques to dispose organic materials have been used over the last three decades. Superintendents have preferences or regional issues affect the disposal method used. In the 1930's and 1940's most of the grass clippings, leaves, and other organic materials were composted. For various reasons, but mainly due to different maintenance routines that are being used today, composting is now used very rarely. In recent years, the use of composting methods is regaining popularity, because of changing laws in many states. The current practice of hauling organic materials to public landfills will not be feasible anymore, because the laws have been changed so that only inorganic materials are being accepted from 1993 on (Tracinsky, p.1).

One disposal technique is to very thinly spread grass clippings in and out of play areas. It requires skilled personnel to do so, but is very
important because it speeds decomposition. Mower operators have to make decisions effecting golf play directly, because they choose the areas of disposal (Witteveen, p. 67). Another possible disadvantage is thatch build up in these areas. Even so, this method of disposal offers the advantage of not having to collect grass clippings and haul them away.

Current practice is also, in rural areas, to have grass clippings and leaves picked up by farmers. Organic materials are then stored by farmers on their property and composted for a short period of time. After several weeks, when the materials are decomposed, the farmer applies them to the fields as fertilizer. This disposal method has the advantages of the farmer not having to buy expensive artificial fertilizers, and golf courses disposing of organic materials without extra costs.

Some of the disposal methods described above offer benefits for golf courses, other often do not. Organic materials take up landfill space. Composted grass clippings and leaves can be used as topdressing and topsoil on golf courses and help reduce maintenance costs. Superintendents must get more and more involved in on site composting operations and in the use of decomposed materials on the courses. Composting does not only solve the clipping and leaf disposal problem, but is beneficial to maintenance budgets and the environment.

Two alternatives, aside from spreading grass clippings, for example, in out
of play areas as done on The Ohio State University Golf Courses, seem to be practical. First, the rediscovery of composting and, second, the use of mulching mowers. Composting offers the advantage of using organic materials that can be used as topdressing, fertilizer, or topsoil. Mulching mowers leave the cut clippings on the turf, resulting in better growth and thicker root systems.

Composting was common when the game was first introduced in America, but was lost because of the discovery of chemicals that helped control the growing process and quality of the turf (Mascaro, p.28). On site composting programs turn organic materials into valuable soil enricher. The process can be incorporated in existing maintenance operations fairly easily and can have economical benefits. The costs for composting one ton of organic material is $15-20 (Perry, p.31). Grass clippings, the largest amount of organic material generated on courses, decompose rapidly because they contain 85 percent water. The resulting soil is rich in nutrients, and, when mixed with sand, can be used as topdressing. Composting operations turn a problem into valuable resources. They are not very labor intensive and eliminate chemicals.

Leaves and small branches, which are a major maintenance concern during the fall season, can also be incorporated into composting routines. Leaves on greens and fairways are a breeding ground for diseases and frustrate golfers by slowing down the play (Quinn, p. 23). Quick pick up of the leaves is essential. They are usually blown into out of play areas and
then collected by turf sweepers.

The organic materials are to be collected with small trailers from piles left by the mower operator on the site of the fairways and then transported to the disposal or composting areas. The size for the composting site should be $2/3$ of an acre of cultivated sandy loam for a regular size 18 hole golf course. The next step is to spread out the grass clippings, leaves, and small branches as thinly as possible. Lime is used to control odor and pH value and to speed decomposition of the materials. Piles for sod and soil should be separated from the ones for grass and leaves. The surface of the piles should be left reasonably dry to control odor. Good drainage and air movement is essential for quick decomposition. Piles need to be moved about once every six weeks. During the composting process the volume of the organic materials reduces tremendously (Tracinsky, p.4). After one golf season, the piles should winter over, be turned again and then screened. The organic material can then be mixed with sand and used as topdressing or topsoil.

Mulching mowers were very popular in the 1970's, but because of technical problems, they only have been used sporadically over the last seventeen years (Gibson, p.14). Today, mulching mowers are one valuable alternative in grass clipping disposal. Mulching mowers make mowing less time consuming and burdensome because grass clippings do not have to be collected or spread in and out of play areas. By returning nutrients to the turf,
organic materials are eliminated on landfills. One disadvantage of mulching mowers is that they should not be operated on wet turf, because the cut grass gets stuck in the mowing decks. Due to the fact that the courses are mowed during the early morning hours, mulching mowers can not be used at this time. On the other hand, during dry summer periods when they can be used, they help reduce the amount of grass clippings that need to be disposed. Mulching mowers chop grass into half inch pieces or smaller as they move through the deck several times. These fine chopped clippings can then work their way into the grass and return valuable organic material back to the turf. Grass clippings are 20-30 percent protein, which are attacked by bacteria resulting in a fast decomposition process that allows evaporation at the soil level. These small particles do not lead to thatch build up. Mulching with mowers produces a greener and healthier lawn, because mulch particles are absorbed by the grass root system in fourteen days (Perry, p.31).

The Ohio State University Golf Courses should explore these mulching alternatives, eventhough the disposal techniques currently used seem to be inefficient. Used in combination with selective maintenance types, the courses could be at the cutting edge of environmental sound maintenance routines.

Computer video image enhancement techniques can be used to find suitable areas for composting operations. The visual impact of compost piles can be analyzed effectively from various viewpoints.
The possible location of compost areas might be limited on the courses, which make visual impact studies even more important. Possible screening alternatives for this area can also be explored.

**NOT PLAY RELATED OPEN LAND MAINTENANCE**

Only 70 percent of the total golf course property average is used for playing golf and the 30 percent that remain is not play related. The treatment of these areas is an important aspect of golf maintenance and management. Out of play areas are rarely treated as such, because of the attitude of golfers towards golf course maintenance. Do golfers consider any area out of play? The retrieval of lost balls and unpenalized play often seems to be more important than environmental oriented maintenance routines. Areas considered out of play are mowed too frequently and the grass is kept too short. Wooded areas are cleaned out and the lack of shrubs is evident on many golf courses (Phelps, p.14). Areas, currently used to spread out grass clippings, could be covered with flowers and flowering shrubs and are at many good golf courses. Many of todays golf courses are green, nothing but green.

Current treatment of out of play areas is very expensive. The vast amount of grass clippings that are to be disposed are tremendous. Steps need to be taken to treat out of play areas more naturally. Educating golfer, to appreciate the total environment that golf is played in, is going to be the biggest challenge. There is more to the game of golf than to hit a perfect shot.
The natural environment of the course should also be enjoyed. Out of play areas should be maintained but should also be kept natural.

Maintenance routines used on roughs at The Ohio State University Golf Courses need to be evaluated in terms of their practicality and environmental consciousness. Since roughs are currently treated the same way as fairways, much could be done to change current management practices.

Roughs can be the highlight of the courses by providing color and natural micro climates. Changing the maintenance routines in out of play areas to environmentally sound techniques not only helps in terms of aesthetics, but also keeps costs down because large areas do not have to be frequently mowed anymore. It also helps to solve organic material disposal problems.

The introduction of wildflowers in out of play areas has become common practice on some of the better courses which emphasize a link to nature. Wildflowers are native flowering plants that persist in a location without, or in spite of, human intervention. They require little fertilization, can withstand drought, and provide food and shelter for wildlife. Wildflower plantings are an excellent alternative in transition zones, and grow well in poor soils and diverse conditions (Stack, p.10). Once established, they enhance the deep rough areas and provide erosion control where needed. These areas require almost no maintenance or irrigation and can take care of themselves. Still wildflower areas do need maintenance during the first years when
weed invasion and competition is a major concern.

To install wildflowers in out of play areas, the common procedure would be to leave large areas of tall fescue turf unmowed. After a few months, wildflowers can then be introduced through hydro seeding. Treating concerned areas with herbicide, a month before seeding, keeps the weeds under control. Another method is to remove sections of sod for a relatively weed free area in which to plant flowers. Areas can be planted exclusively with perennials, annuals, or a combination of both, depending on specific site criteria. To choose native naturalized annuals in combination with perennials is highly desirable, because they provide color for long periods during the growing season and in suitable growing conditions many reseed year after year (Stroud, p.30). Weed control is a major factor in having successful wildflower areas. During the planning process, bloom periods, height, and color of wildflower species should be considered. Height is of special importance because of the possible obstruction of play.

The introduction of wildflower areas have not only benefited the environment, but also golfers. They can identify targets better and are being rewarded for having executed a shot exactly as planned. In case players lose their golf balls in wildflower areas, the rule should be not to seek to retrieve the ball.

Video image enhancement techniques of the computer can be used effectively to study the impact of wildflower areas. Images can be used to evaluate
visual impact, and possible interference with play. On courses where wildflowers in the rough have never been introduced, it is also helpful to use image enhancement techniques during the decision making process. Realistic images of proposed conditions can convince golfers and management groups of the benefits and aesthetic qualities of such areas.
CHAPTER V

CONCLUSIONS

There are three major components to this thesis: First computer based three-dimensional modeling and video image enhancement applications for prototypical golf course management and design enhancement programs, second the evaluation of these applications in terms of their effectiveness during design phases, and third, studying the impact of computer generated before and after images on decision making processes during client presentations.

MANAGEMENT PROGRAMS

One purpose for exploring the use of computer technology for the development of prototypical golf course management and enhancement programs was to see if the development of alternative management routines can benefit from the use of three-dimensional modeling and video image enhancement techniques.

Improvement programs should be developed using computer technology to evaluate alternative solutions to maintenance and management routines. It is important to have accurate information about the sufficiency of maintenance techniques currently used in order to effectively introduce
alternative techniques or procedures. Computer based three-dimensional modeling and video enhancement techniques are very effective for visual impact studies and spatial character analysis, because such accurate and realistic before and after images can be generated.

The generation of three-dimensional models of golf courses is time consuming, especially if data from maps have to be converted into digital format. To be really useful, databases containing information regarding the exact location of trees, fairways, bunkers, tees, greens, and three-dimensional surface models need to be established. The total time involved depends, of course, on the size of the project and the level of accuracy desired. Since wire frame drawings from ACAD can be difficult to interpret, shaded surface models should be generated. The creation of these models is burdensome, because 3d-faces have to be manually laid exactly onto the grid representing the topography if not done automatically. If this is not executed with great care, the generated models will be visually faulty.

Once drawings are generated, the computer based three-dimensional modeling techniques of the computer are very effective and easy to use. Design alternatives can be evaluated from any angle and distance. New scenes can be generated quickly and easily. The impact of proposed solutions based on interference with play or impact on spatial enclosures can be evaluated.
To generate mathematically correct images of proposed solutions, wire frame drawings have to be laid on top of video or photographic images, and then rendered. In order to do so, viewpoints from which spaces are observed, in the wire frame drawing as well as in the image showing existing conditions, have to match exactly. To find the exact location in drawings and on the courses can be difficult. Studying and comparing the amount of spatial enclosures created by alternative planting schemes or the visual impact of different cart path alignments can, for example, be performed very well, because images generated show alternatives at near photo realistic quality. For example, the impact of introducing wildflowers into an area can be evaluated with video enhanced images to convince management groups that interference with play would be kept to a minimum.

Computer applications can enrich the process of evaluating current management practices. They should be incorporated in long range management and enhancement programs, because of the valuable role and impact they can have on the evaluation of design alternatives. Three-dimensional modeling and video image enhancement techniques on the computer can influence the establishment and use of long range management and enhancement programs positively, because of the chance to show alternatives realistically and the ease with which they can be incorporated.
COMPUTER ASSISTANCE DURING THE DESIGN PHASE

The 3D modeling and video image enhancement applications of the computer are of great help during the design phase. Generated surface models allow the designer to explore natural and proposed environments in the third dimension. Many design alternatives can be explored with computer generated models, because changes can be made with ease once drawing files have been created. Before and after models, which can be quickly viewed from many different angles, are used to evaluated the impact of different alternatives. These models can easily be changed and modified, until desired solutions are found. After images, generated based on the created surface models, can be used to evaluate the visual impact of alternatives realistically.

Even though video images are not absolutely necessary during the design phase, they still give the designer a better, more realistic idea of design alternatives. The combination of three-dimensional modeling and video image enhancement is very effective. Since the generation of computer video images is not very time consuming, they can be beneficial for the designer during the design phase, and the use of these images is strongly encouraged.

COMPUTER ASSISTANCE FOR DECISION MAKING PROCESSES

The introduction of alternative management and design solutions on golf courses is often difficult, because the different alternatives can not be evaluated. Computer based three-dimensional
modeling and video enhancement techniques can be used very effectively during decision making processes, because the generated images show different design solutions realistically. Using such simulations management groups that can base their decisions on realistic images and will be able to evaluate the impact of the proposed changes before they are introduced to areas of concern. Discussions about the suitability of proposed alternatives often start immediately, because even inexperienced viewers have a sense of place - they can comprehend the new environment easily.

Computer based three-dimensional modeling and video enhancement applications will encourage the establishment and use of long range management and enhancement programs. Still, the users should be aware of the fact, that while computer generated images create an illusion of photo realistic reality, they are only as accurate as the data used to generate them.
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