Use of modern design methodologies in natural resource systems*

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Many of the engineering students at The University of Georgia (UGA) have a primary interest in natural resource design. While there is an abundance of instructional materials concerning modern design methodologies, this material is concentrated on design of mass-produced products. Thus, the student with an interest in natural resources is not gaining an appreciation of the impact that modern design has on engineering activity. This manuscript describes how the Stepwise Procedure for Incorporating Environmental Consideration into Engineering Solutions (SPIECES) was used to solve this problem.

INTRODUCTION

TODAY'S UNDERGRADUATE engineering curriculum commonly contains a series of courses that are focused primarily on modern design methodology. In freshman and sophomore courses, lectures are dedicated to the fundamentals of design where students develop an understanding of concepts such as concurrent design and of design tools such as Quality Function Deployment. In junior and senior courses, students learn to apply those concepts and tools using term projects that simulate the job responsibilities found in the engineering profession. Today's instructors have a rather large selection of references that can assist them in developing lectures on modern design and that can be used as course textbooks. However, the engineering faculty at The University of Georgia (UGA) has found that most modern design methodologies are concentrated on the design manufacturing and mass-produced products and do not lend themselves directly to involving natural resource systems. Many of the UGA engineering students who have a primary interest in natural resource systems are not obtaining a full appreciation of the impact that modern design methodologies will have on their future engineering activities. This lack of appreciation, if left unchecked, could have negative results on both the professional development of students graduating from the UGA engineering program and the curricula's ability to the general education criteria specified by the Board of Directors of the Accreditation Board for Engineering and Technology EC-2000 documents.

Several design methodologies are focused on society's concern for the environment. For example, green engineering [1] approaches environmental issues as objectives, and not constraints, of the design. The general goals here are waste reduction, material management and pollution prevention as a product enhancement. Design for the environment [2], design for recyclability [2] and industrial ecology [3] are other major design methodologies focused on the environment. However, all of these design methodologies are still primarily tools focused on manufacturing a product in an environmental friendly manner and are not focused toward forest and food resources. Axiomatic design [4] is an approach that is applied to both the manufacturing setting and natural resource setting. However, instruction in these principles seem to be better suited for upper-level students who first have gained experience in other methodologies. Quality Function Deployment (QFD) [5] is a methodology initially developed for a product manufacturing setting, but it has been found that QFD principles are easily applied to other schemes such as organizational design [6].

Realizing the potential of applying the principles of QFD in natural resource systems design, the authors developed a design process called the Stepwise Procedure for Incorporating Environmental Consideration into Engineering Solutions (SPIECES) [7]. Using the UGA capstone engineering design course, it was found that SPIECES was easily understood by undergraduates and that SPIECES helps undergraduates to appreciate the need to apply modern design theory in natural resource systems. The purpose of this manuscript is to report how these results were achieved.
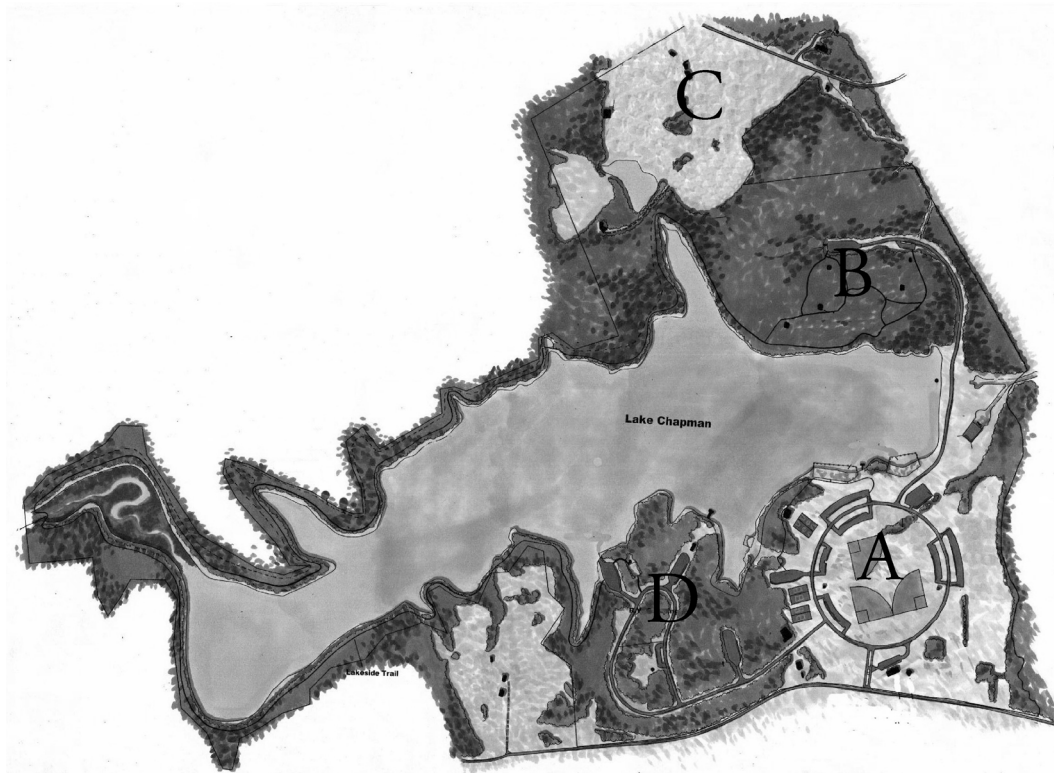
Fig. 1.

ENGINEERING AT UGA

The University of Georgia (UGA) offers two engineering four-year ABET-accredited BS degrees: Biological Engineering and Agricultural Engineering. The Biological Engineering degree has three areas of emphasis – bioprocessing, biomedical, and environmental, whereas the Agricultural Engineering degree has five areas of emphasis – material processing, structural systems, mechanical systems, electrical systems and natural resources. As of 1999, total enrollment in these programs was approximately 250 undergraduates. UGA has strengths in the areas of agriculture, biology and ecology. Over 30% of the UGA engineering faculty have research programs focused primarily on natural resource systems. This emphasis naturally has resulted in over 50% of the UGA engineering undergraduates enrolling in either the natural resource emphasis area or the environmental emphasis area.

As typical of most US engineering BS degree programs, UGA engineering seniors enroll in a capstone design course where they are required to synthesize their engineering skills on long-term projects. However, unlike most universities, there is only one capstone design course taught at UGA with the participating students coming from the two curricula and from all emphasis areas. To allow students to work on a problem associated with their particular emphasis area, multiple projects are available.

THE DESIGN PROJECT: NATURAL RESOURCE SYSTEMS DESIGN

Sandy Creek Park in Clarke County Georgia USA, is a regional recreational area that allows citizens to experience nature. The park is located within 10 miles of the University of Georgia and supports many extracurricular activities of the university. The park area currently consist of 634 acres of grass and wood land surrounding a 346 acre Public Law 566 watershed control structure, Lake Chapman (Fig. 1). The park owns an additional 82 acres of pastureland that is available for expansions as defined by the project presented herein. In 1986, over 90,000 people visited Sandy Creek Park. According to the County Planning Head, population projections indicate that over 220,000 people could visit the park in the year 2025.

In the fall of 1998, the park managers were approached to discuss possible projects for the department's capstone design course. A new graduate from our Agricultural Engineering BS degree program was hired to analyze the overall function of Sandy Creek Park and to assess the park's current status and needs. It was found that the current park facilities were designed on an as-needed basis, and that the current master plan for the park, developed in 1978, was antiquated and was not meeting current or future needs. A functional analysis of current park activities is given in Table 1.

Table 1. Decomposition of the park functions was used to determine the projects for the capstone design course.

1. Lake access
1.1. Fishing
1.1.1. Parking
1.1.2. Standing/Dock area to fish from
1.1.3. Providing security
1.2. Boating
1.2.1. Parking vehicle and trailer
1.2.2. Unloading/loading boat
1.2.3. Docking boat
1.2.4. Providing security
1.3. Swimming
1.3.1. Sunning on beach
1.3.2. Walking on beach
1.3.3. Playing on beach
1.3.4. Swimming in lake
1.3.5. Showering
1.3.6. Using the restroom
1.3.7. Parking car
1.3.8. Providing security
1.4. Pet runs
1.4.1. Walking
1.4.2. Running
1.4.3. Training
1.4.4. Confining
1.4.5. Swimming
1.5. Camping
1.5.1. Family Camping
1.5.1.1. Sleeping
1.5.1.2. Picnicking
1.5.1.3. Parking
1.5.1.4. Unloading/loading
1.5.1.5. Building a fire at site
1.5.1.6. Cooking/Eating
1.5.1.7. Nature recreation
1.5.1.8. Swimming
1.5.1.9. Restroom
1.5.1.10. Seclusion/quiet time
1.5.1.11. Security
1.5.2. Group camping
1.5.2.1. Functions are the same as Family camping
1.5.3. Tent camping
1.5.3.1. Functions are the same as Family Camping
1.5.4. RV camping
1.5.4.1. Functions are the same as Family Camping
1.6. Trails
1.6.1. Walking
1.6.2. Jogging
1.6.3. Hiking
1.6.4. Riding horses
1.6.5. Pushing wheelchairs, strollers
1.6.6. Providing security
1.6.7. Providing quiet, natural and secluded trail
1.7. Group/Special Events
1.7.1. Catering
1.7.2. Loading/unloading area
1.7.3. Conference meeting
1.7.4. Parking
1.7.5. Traffic control
1.7.6. Providing restroom facilities
1.8. Visitor Center
1.8.1. Providing conference facilities
1.8.2. Providing staff office space
1.8.3. Providing kitchen cooking area
1.8.4. Providing restroom facilities
1.8.5. Parking
1.8.6. Park information
1.8.7. Fee collection

Agreements were made with the park manager that a redesign of the park's master plan was needed, and that this redesign would be a good project for UGA engineering students to apply modern design procedures to a land use/management design. It should be noted that in the UGA capstone design course other student work involving this park included new and redesigns of seven

Problem Definition

Step 1. The design need
Step 2.   Identifying the stakeholder
Step 3. Determining the stakeholder requirements
Step 4. The relative importance of stakeholder requirements
Step 5. Benchmarking to existing designs
Step 6. The improvement ratio
Step 7. The engineering requirements
Step 8. The relationship matrix
Step 9. The correlation matrix
Step 10. The design specifications

Concept Evaluation

Step 11. The deviation index
Step 12. The composite value
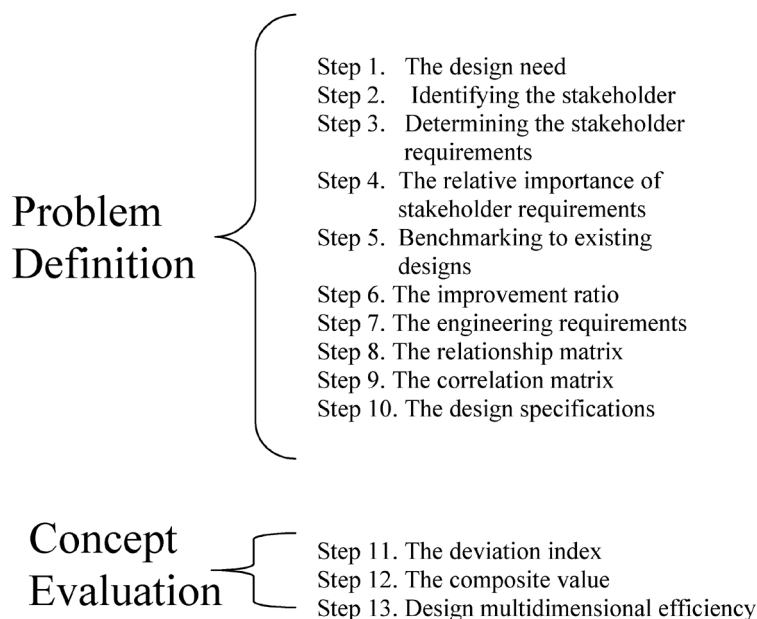Step 13. Design multidimensional efficiency

Fig. 2. The steps of the Stepwise Procedure for Incorporating Environmental Consideration.

major park facilities. For convenience, this manuscript will focus on the redesign of the park's master plan with respect to a new recreational vehicle (RV) campground.

THE STEPS OF SPIECES

Quality Function Deployment (QFD) [6] is the framework for the Stepwise Procedure for Incorporating Environmental Consideration into Engineering Solutions (SPIECES) [7]. The steps of SPIECES described herein are given in Fig. 2.

These steps were used to determine the constraints to be placed on a new master plan for Sandy Creek Park, to translate the qualitative constraints typically specified by the stakeholders into the measurable constraints needed by the design engineer and to determine which conceptual solution had the greatest potential to satisfy the constraints. However, SPIECES is an iterative process that should not be overlooked. At any given step, new information may be obtained and affect previous steps. In the project presented here, the students found that previous completed steps had to be modified as more information was found. The following paragraphs describe these steps but not the iterative process.

Step 1
The initial step of developing the design requirements is determining what is the need that the design solution must fulfill. The design need statement developed by the students was:

> Develop a layout and management system for Sandy Creek Park, solving current problems and projection of its needs into the future for the next 25 years, while preserving the park's environmental ideals.

This statement provides the basis for a final assessment of the project.

Step 2
Once the need is identified, the design engineer determines who are the stakeholders of this need. Stakeholders drive the development of design constraints, can influence the actual quality of the end product and/or will judge the success of the end product. A primary stakeholder has direct control over the product. A secondary stakeholder has indirect control but who can influence the end

product. Table 2 lists the stakeholders identified for the Sandy Creek master plan design.

Step 3
Although a need statement was developed to identify the stakeholders of the design, it is not necessarily useful for determining the attributes that the stakeholder will use to scrutinize the success of the design. Herein, these attributes will be called Stakeholder Requirements (SRs). The principles of QFD [6] suggest that the SRs are best obtained using an open-ended question. For this design, the stakeholders were asked: 'What are the qualities needed in a RV campground that maintains the environmental integrity of Sandy Creek Park?'

Each of the stakeholders listed in Table 2 was asked to answer this question. Focus groups were used to gain information from the general public and from UGA students. Also, weekend visits to the park were used to interview the park users. However, Sandy Creek Park currently does not have RV camping facilities and therefore, stakeholders who are users of recreational vehicles had to be interviewed at other regional parks. All interviews were oral with the design engineers recording the comments. Table 3 provides the SRs for this project.

Step 4
Next, it was necessary to rank each SR in terms of their relative importance to each other. The ranking of importance allows the designer to judge which SR must be fulfilled to insure design success and which SR may be left out without detrimental effect of the design success. A pairwise comparison procedure [6] was used to determine this ranking (Table 4). However, each stakeholder may rank the SRs differently, and not all stakeholders have the same influence on the success of the final design. Therefore, it was necessary to find a weighted average of the SR importance ranking. This weight was based on the importance of the stakeholder.

On this project, a pair-wise comparison indicated that the public user had a 20% weight, the park management a 40% weight, Athens-Clarke County Department of Leisure Services a 30% weight, and UGA students a 10%

Table 2. The list below identifies the stakeholders for the Sandy Creek Park Master Plan design project as defined by the student engineers.

Primary Stakeholder	Secondary Stakeholder
Park Manager	General Public/Users of the park facilities
Athens-Clarke County Department of Leisure Services oversight department for Sandy Creek Park.	The University of Georgia Students

Table 3. The stakeholder requirements used in this design project.

- Ability to handle large groups
- Accessible to public
- Close to park entrance
- Preserves natural setting
- Provide peace and tranquility
- Preserves biodiversity
- Preserves beauty of park
- Low cost
- Accessible to restroom
- Has RV utilities
- Has security

Table 4. The relative importance of each stakeholder requirement (SR) was determined using pair-wise comparisons. Using these comparisons, each SR was ranked as a percentage of importance, summing to 100% as shown at the bottom of the column. Not all stakeholders have the same influence on the success of the final design. Therefore, a weighted average of the SR importance ranking was calculated where the weight was based on the importance of the stakeholder. This level of influence is indicated under the name of the stakeholder and is given as a percentage.

Stakeholder Requirements	Public User 20%[#]	Park Management 40%	Leisure Services 30%	UGA Students 10%	Weighted Average of the Ranking of SR Importance
Ability to handle large groups	7%	9%	14%	5%	10%
Accessible to public	6%	7%	13%	9%	9%
Close to park entrance	7%	2%	1%	4%	3%
Preserves natural setting	12%	15%	15%	12%	14%
Provide peace and tranquility	11%	13%	8%	14%	11%
Preserves biodiversity	12%	16%	12%	13%	14%
Preserves beauty of park	6%	18%	16%	18%	15%
Low cost	10%	5%	5%	12%	7%
Accessible to restroom	6%	2%	3%	5%	3%
Has RV utilities	19%	2%	5%	3%	6%
Has security	4%	11%	8%	5%	8%

weight. Using this weighting scheme, the four SRs considered most important were:

- preserves beauty of the park;
- preserves natural setting;
- preserves biodiversity;
- provide peace and tranquility.

Step 5

Once the SRs were determined and ranked, it was important to examine the park's current ability to provide RV camping and to identify SRs that could be improved upon. Three grass fields allocated for sports such as soccer are often used for limited RV camping during special events. Table 5 rates this situation for possibly satisfying the SRs. This activity indicated that the current use of these fields for RV camping met very few if any of the SRs.

Step 6

Improvement ratios were calculated to help identify the SRs that have greatest impact on perceived product success. First, the students

determined how well the developed design would fulfill individual SRs (Table 5). This is known as developing the target for the design. The Improvement Ratio (Table 5) is calculated by determining the ratio of the design target to the rating determined in Step 5 and multiplying this ratio by the SR importance ranking (Step 4).

On this design project, the students found that the greatest potential for a successful master plan design would occur if they focused on the four SRs above. This did not mean that the other requirements could be ignored; it just indicated where design effort should be placed for greatest impact.

Step 7

Once the potential to improve the current design was determined, the students had to decompose the SRs into the measurable engineering requirements (ERs). These measurable requirements are used by the engineer to predict design success. As an example, a typical SR for a mass-produced product may be 'easy-to-assemble'. This SR can be described by measurable engineering requirements (ERs)

Table 5. The park's current ability to satisfy the stakeholder's requirements (SR) for RV camping was ranked using a 1-5 scheme. This benchmarking helped to determine which SRs would have the greatest impact on success of the final design. A 1 indicates that the SR was not satisfied by the benchmark. A 5 indicates that the SR is completely satisfied by the benchmark. The center column indicates the target that a conceptual solution should have for satisfying the SR. The right-most column indicates the SRs that a new design should satisfy in order to have the greatest potential for success.

Stakeholder Requirements	Benchmark: RV camping on the grassed sport fields	Target Design	Weighted Average of the Ranking of SR Importance	Improvement ratio
Ability to handle large groups	2	4	10%	20%
Accessible to public	3	4	9%	12%
Close to park entrance	3	3	3%	3%
Preserves natural setting	1	4	14%	56%
Provide peace and tranquility	1	4	11%	44%
Preserves biodiversity	1	4	14%	56%
Preserves beauty of park	1	4	15%	60%
Low cost	4	3	7%	5%
Accessible to restroom	3	3	3%	3%
Has RV utilities	1	3	6%	18%
Has security	2	4	8%	16%

such as: number of parts; number of joints to be connected; number of tools needed to assemble; assembly time. Similarly, measurable ERs may describe environmental SRs. For example, 'diversity of an ecosystem' may be described by:

- number of animal species,
- number of plant species,
- number of aquatic species,
- density of tall trees,

just to name a few. Esteghlalian, et al. [7] provides several measurable ERs for SRs typically used by stakeholders of natural resource systems and was used by the students on this project. Table 6 provides the ERs used herein to describe each SR.

Step 8

Once the first iteration of the above steps was completed, the information was arranged in matrix form (Table 7). The matrix was used to show the relationship between the SRs and ERs. Using a 0 to 3 numbering system, the students were able to indicate the strength of these relationships.

In its final form, this matrix indicated a single measurable ER which could describe more than one qualitative SR. For example, the RV campground area, the second ER in Table 7, has a large influence in meeting the four stakeholder requirements:

- ability to handle large groups;
- preserves biodiversity;
- preserves the beauty of the park;
- low cost.

This is very important when ranking the conceptual solutions to the problem, as shown later.

The three engineering requirements that the student used to quantify the SR 'preserves biodiversity' could not be measured during the semester time frame of this project and thus were not included in the matrix. These ERs were: number of animal species; number of plant species; number of food chains. These must be determined before actual implementation of the design solution.

Step 9

A correlation matrix between the ERs was developed during this project but size constraints of this manuscript do not allow it to be presented here. However, the reader should note that adjusting any one ER might have positive or negative impact on other ERs. For example, if the 'campground area' target is decreased, then the requirements 'cost to build' and 'area covered by lighting', could decrease. The correlation matrix is an important feature and should not be overlooked. The authors suggest that the reader refer to Ullman's textbook for guidance [5].

Step 10

The last row shown in Table 7 provides the target values for each engineering requirement (ER). These are often referred to as design specifications and are the final form of the problem definition phase of design.

Concept generation produced four possible sites for the new RV campground (Fig. 1). Concept A places the campground on the current sports fields and would convert these fields for the needed RV utilities. Concept B places the campground on the eastern side of Lake Chapman within the current primitive tent camping area. Concept C used the park's 82 acres of pastureland that is not being used at this time. Concept D places the campground within a wooded lot on the western side of Lake Chapman, between the park's Tot Lot playground and the BBQ building.

During concpets evaluation, SPIECES [7] makes use of multivariable analysis [8] and scores concepts based on Table 7's relationship matrix scores and SR importance ratings.

Step 11

First, the students evaluated each concept to see if it would produce a solution that met the ER design specification values. For each ER, it was estimated that the concept would produce a solution that was better than, equal to or worse than the design specification. This information (Table 8) was used to calculate a deviation index; a term that

Table 6. Each stakeholder requirement (SR) was described by one or more measurable engineering requirement (ER). Some ERs were used for more than one SR.

Stakeholder Requirements	Engineering Requirements
Ability to handle large groups	RV camping area, Square footage per RV site, Distance from restroom, Traffic load
Accessible to public	Cost to camp
Close to park entrance	Distance from park gate, Distance to visitor center, Distance from lake, Distance from beach
Preserved natural setting	Square footage per RV site, Distance from lake, Distance from beach, Number of tall trees, Number of scrubs, Area covered by plants, Area covered by lighting, Traffic load
Provide peace and tranquility	Distance from playground, Square footage per RV site, Distance from lake, Distance from beach, Number of tall trees, Number of scrubs, Area covered by plants
Preserved biodiversity	Number of animal species, Number of plant species, Number of food chains, RV campground area, Number of tall trees, Number of scrubs, Traffic load
Preserved beauty of park	Area covered by plants, Number of tall trees, Number of scrubs, Number of food chains
Low cost	RV campground area, Cost to build, Cost to camp
Accessible to restroom	Distance to restroom, Distance to visitor center
Has RV utilities	Distance to park gate, Square footage per RV site, Cost to build
Has security	Distance to visitor center, Distance to park gate, Distance to telephone, Area covered by lighting, Cost to build

Table 7. The relationship matrix indicates the engineering requirements (ERs) that are used to describe the stakeholder requirements (SRs). More than one ER can be used to describe one SR. The strength of the relationship is indicated by the 0, 1, 2, and 3 with 0 indicating no relationship and 3 indicating a very strong relationship.

STAKEHOLDER REQUIREMENTS	Weighted Average of the Ranking of SR Importance	distance to playground (61 m)	RV Campground Area (10900 m²)	square footage per RV site (145 m²)	distance from lake (61 m)	distance from beach (61 m)	distance from restroom (122 m)	distance to park gate (1600 m)	distance to visitor center (2400 m)	distance to telephone (400 m)	Number of tall trees per 100 m² (10)	Number of shrubs per 100 m² (1)	Area covered by plants (not grass) (20%)	Area covered by lighting (15%)	traffic load: number of cars per hour (20)	cost to build ($152,000)	cost to camp ($5)	Benchmark: RV camping on the grassed sport fields	Target Design
Ability to handle large groups	10%	1	3	2	2	0	2	0	0	0	2	2	2	0	3	2	2	2	4
Accessible to public	9%	1	2	2	2	2	0	2	0	0	0	0	0	0	2	0	3	3	4
Close to park entrance	3%	0	1	2	3	3	1	3	2	0	0	0	0	0	2	2	0	3	3
Preserves natural setting	14%	1	2	3	2	3	2	1	1	0	3	3	3	2	3	2	0	1	4
Provide peace and tranquility	11%	3	2	3	3	3	2	2	2	1	3	3	9	3	3	2	0	1	4
Preserves biodiversity	14%	1	3	3	3	3	1	1	1	0	3	3	3	2	3	2	0	1	4
Preserves beauty of park	15%	1	3	3	3	2	2	2	1	0	3	3	3	2	3	2	0	1	4
Low cost	7%	0	3	3	1	0	2	1	2	2	2	2	2	2	2	3	3	4	3
Accessible to restroom	3%	1	1	1	0	0	3	0	1	0	0	0	0	0	0	1	0	3	3
Has RV utilities	6%	0	1	3	0	0	0	0	0	0	0	0	0	0	0	1	3	1	3
Has security	8%	1	0	1	3	3	3	3	3	3	3	3	2	3	2	2	1	2	4

Table 8. The deviation index indicates the ability of each concept to meet each engineering requirement (ER). When the deviation index equals 1, then the concept meets the design specification for that particular ER. If the concept does not meet the design specification for a particular ER, then the deviation index for that ER is the absolute value difference between the design specification and the value produced by the concept.

	Distance from playground, m	RV Campground area, m²	Square footage per RV site, m²	Distance from lake, m	Distance from beach, m	Distance from restroom, m	Distance from park gate, m	Distance from visitor center, m	Distance from telephone	Number of tall trees, # / m²	Number of shrubs, # / 5m²	Area covered by plants (not grass), %	Area covered by lighting, %	Traffic load, # cars / hr	Cost to build, $	Cost to camp, $
Design specifications	61	10900	145	61	61	122	1600	2400	400	10	1	20%	15%	20	152000	5
Concept A	91	14400	145	60	61	61	91	80	80	0	0	0	30	60	175000	5
Concept B	300	3734	145	24	250	250	500	450	450	10	1	70	10	15	250000	15
Concept C	420	12554	145	200	350	350	700	600	600	2	0.25	30	15	10	450000	15
Concept D	20	25000	145	60	120	30	240	300	300	8	1.25	40	10	15	17500	7
Is Concept A better than or equal to the target	no	yes	yes	yes	yes	yes	yes	yes	yes	no	no	no	yes	no	no	yes
Deviation Index For Concept A	30	1	1	1	1	1	1	1	1	10	1	20	1	40	23000	1

describes the deviation of the concept from the desired design specification. If the conceptual solution met or was better than the design specification, then the deviation index for that particular ER was the value 1. If the estimated value for that particular ER was worse than the design specification, then the deviation index is the absolute value difference between the estimate and design specification. For example, for the engineering requirement 'campground area', Concept A is estimated

Table 9. The composite value incorporates the relationship matrix scores and the importance ratings into concept evaluation. This value combines the index scores for each engineering requirement into a single score for the stakeholder requirement.

	distance to playground	RV Campground Area	square footage per RV site	distance from lake	distance from beach	distance from restroom	distance to park gate	distance to visitor center	distance to telephone	Number of tall trees	Number of schrubs	Area covered by plants (not grass)	Area covered by lighting	traffic load	cost to build	cost to camp	Sum of the Composite Values in this table	Sum of the Relationship Scores in Table 7	Composite Value
Ability to handle large groups	0.03	3.00	2.00	2.00	0.00	2.00	0.00	0.00	0.00	0.20	2.00	0.10	0.00	0.08	0.00	2.00	13.4	23.0	0.58
Accessible to public	0.03	2.00	2.00	2.00	2.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	3.00	13.1	16.0	0.82
Close to park entrance	0.00	1.00	2.00	3.00	3.00	1.00	3.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.1	19.0	0.79
Preserves natural setting	0.03	2.00	3.00	2.00	3.00	2.00	1.00	1.00	0.00	0.30	3.00	0.15	2.00	0.08	0.00	0.00	19.6	31.0	0.63
Provide peace and tranquility	0.10	2.00	3.00	3.00	3.00	2.00	2.00	0.10	2.00	1.00	0.30	3.00	0.45	3.00	0.08	0.00	25.0	44.0	0.57
Preserves biodiversity	0.03	3.00	3.00	3.00	3.00	1.00	1.00	0.03	1.00	0.00	0.30	3.00	0.15	2.00	0.08	0.00	20.6	32.0	0.64
Preserves beauty of park	0.03	3.00	3.00	3.00	2.00	2.00	2.00	0.03	1.00	0.00	0.30	3.00	0.15	2.00	0.08	0.00	21.6	33.0	0.65
Low cost	0.00	3.00	3.00	1.00	0.00	2.00	1.00	2.00	2.00	0.20	2.00	0.10	2.00	0.05	0.00	3.00	21.4	30.0	0.71
Accessible to restroom	0.03	1.00	1.00	0.00	0.00	3.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.0	8.0	0.75
Has RV utilities	0.00	1.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	7.0	8.0	0.88
Has security	0.03	0.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	0.30	3.00	0.10	3.00	0.05	0.00	1.00	26.5	36.0	0.74

Table 10. Design Multidimensional Efficiency (DME) scores help to rank the concepts according to the potential for providing a solution to the design problem. Scores closer to 1 indicate better solutions.

Stakeholder Requirements	Composite Value	Weighted average of the ranking of SR Importance	Composite value times SR importance
Ability to handle large groups	0.58	10%	0.06
Accessible to public	0.82	9%	0.07
Close to park entrance	0.79	3%	0.02
Preserves natural setting	0.63	14%	0.09
Provide peace and tranquility	0.57	11%	0.06
Preserves biodiversity	0.64	14%	0.09
Preserves beauty of park	0.65	15%	0.10
Low cost	0.71	7%	0.05
Accessible to restroom	0.75	3%	0.02
Has RV utilities	0.88	6%	0.05
Has security	0.74	8%	0.06

Conceptual Solution	Design Multidimensional Efficiency Score
A	0.68[#]
B	0.59
C	0.44
D	0.73

[#] The sum of the rightmost column shown the chart above.

to provide 14400 m^2, and this was determined to be better than the design specification of 10900 m^2. Therefore, the deviation index for campground area is 1. However, Concept A does not meet the design specification for the ER 'distance from playground'. Therefore, the deviation index for this requirement is 30; in other words the difference between the desired design specification and the estimated value for the concept.

Step 12
Next, a composite value was calculated (Table 9) where the calculated value was used to evaluate the potential of each concept. The usefulness of this composite value was based on its ability to incorporated the relationship matrix scores and the importance ratings of the SRs thereby relating the evaluation directly back to the SRs. Here, each discrete matrix relationship score (Table 7) was divided by its corresponding deviation index (Table 8). For example, the relationship matrix cell for the SR 'ability to handle large groups' and the ER 'distance from playground' had a relationship score of 1. This value was divided by the ER 'distance from playground' deviation index, which is 30 (Table 8). This new value, 0.03, was entered into a corresponding matrix cell in Table 9. This calculation was done for each matrix cell relating the SR to an ER.

Once this new matrix is completed, the composite value was calculated by dividing the sum of the rows in Table 9 by the sum of the corresponding rows in Table 7. For example, the stakeholder requirement 'ability to handle large groups' had a composite value of 0.58 (13.4 from the sum of the row in Table 9 divided by 23 from the sum of the row in Table 7). These calculations were made for all stakeholder requirements.

Step 13
Now each concept was rated for its potential to be a successful design solution. This was done by multiplying the composite value for each stakeholder requirement by the importance rating for that requirement, and then, summing all of these calculations together (Table 10). This calculation is known as the Design Multidimensional Efficiency (DME) [7]. The DME values for Concepts A, B, C, and D were 0.68, 0.58, 0.44 and 0.73, respectively.

A DME of 1 means that the concept meets all engineering requirements and thus the concept meets all stakeholder requirements. Concepts with higher scores are judged to have the greatest potential for meeting the stakeholder requirements and providing a more successful design solution. However, these scores can not be taken as absolute values. Herein, the difference between Concept A and Concept D was not significant enough to make a final conclusion. In this situation, more information from the stakeholder must be obtained before a final decision is made about these two conceptual solutions. However, Concept C was eliminated as a potential solution since it did not appear to meet as many of the stakeholder requirements as Concepts A and D. Adaptations to Concept B could improve its ranking as a potential solution.

FEEDBACK ON SPIECES

Students
Over 50 undergraduates participated in this capstone design course and provided anonymous comments about the course. Review of these comments indicated that the students liked using the framework of SPIECES and believed that the process helped them to apply modern design to a

natural resource system. Secondly, the students commented that more formal instruction of SPIECES in courses prior to the capstone design course would be helpful. At the time of this project, the students were directed to read manuscripts, published or in preparation, that described SPIECES. It would be wise for SPIECES to be incorporated into our design methodology course that is taught during the sophomore year. Students then would be able to apply SPIECES during their junior and senior years.

Four students who applied SPIECES to the master plan project graduated at the end of the semester and obtained entry level environmental engineering positions. Their initial responsibilities dealt with design or assessment of natural resource systems. Six months after their graduation, these former students were asked to reflect back on their senior design experiences. They commented on the application of modern design techniques in their current activities. One student indicated that using SPIECES helped her to appreciate the need to convert the qualitative stakeholder constraints into measurable constraints and how to work with stakeholders who have different priorities. The positive comments obtained from these former students have lead us to believe UGA engineering students focused on natural resource systems are beginning to develop an appreciation of modern design methodology.

Stakeholders

Three weeks after the completion of the design project, the manager of Sandy Creek Park was asked to survey the park staff and provide summary comments concerning the senior design course. The comments were provided in the form of a letter addressed to one of the course instructors. In this letter, the following comments were given:

1. The [students] acted in a professional manner and produced an extensive plan covering every aspect of growth and trends for this area focusing on minimal environmental impact.
2. This detailed plan and documentation will be used to support our funding request for projects in the next five to twenty years.

Oral communication with the park manager indicated that the final design solution for the park was very satisfactory and seemed to consider the complex issues associated with environmental sustainability and societal acceptance. We believe the application of SPIECES helped to provide such satisfactory results.

FUTURE IMPLEMENTATION OF SPIECES

The size of the UGA engineering program restricts instructional resources and limits the undergraduate curricula to a single sophomore course in design methodology. This limitation has always challenged the faculty since students enrolled in this course wish to learn about modern design for their particular emphasis area. These emphasis areas are structural, processing, mechanical, electrical, biomedical, environmental, biological, and natural resources systems. Prior to the spring semester of 2000, the design methodology has been restricted to Quality Function Deployment (QFD) as presented in the textbook *The Mechanical Design Process* [5]. This mechanical emphasis has not been accepted by the students interested in natural resources. Since SPIECES is an extension of QFD, it can easily be incorporated into our sophomore design methodology course with minimal changes. Based on the reactions from students who have used SPIECES, we believe it will help our students to appreciate the need to apply modern design methodologies in natural resource systems design and that these methods will be acceptable to all of our students. Also, the uniform format of SPIECES with QFD will make it applicable to design projects required in the upper-level courses.

CONCLUSIONS

The Stepwise Procedure for Incorporating Environmental Consideration into Engineering Solutions (SPIECES) [7] helped students in the capstone design course to appreciate the power of modern design involving natural resources. Results indicate that presenting SPIECES earlier in the curricula will benefit the students and should alleviate the faculty concerns expressed above.

REFERENCES

1. B. Samir Billatosf and A. Basaly Nadia, *Green Technology and Design for the Environment*, Taylor and Francis, Washington DC (1997).
2. T. E. Graedel and B. R. Allenby, *Design for Environment*, Princetice-Hall, Inc., Upper Saddle River, NJ (1996).
3. T. E. Graedel and B.R. Allenby, *Industrial Ecology*, Princetice-Hall, Inc., Upper Saddle River, NJ (1995).
4. Nam, P. Suh, *The Principles of Design*, Oxford University Press, New York, NY (1990).
5. D. Ullman, *The Mechanical Design Process,* MacGraw-Hill, New York, N.Y (1997).
6. Lou Cohen, *Quality Function Deployment: How to make QFD work for you,* Addison-Wesley Publishing Company, New York, NY (1995).

7. A. Esteghlalian, B. Verma, T. Foutz and S. Thompson, Incorporation of environmental and societal considerations into engineering design, *Proc. Intelligent Design in Engineering Applications,* Aachen, Germany, (Sept. 1997).
8. R. Chechile, Probability, utility, and decision trees in environmental decision analysis, in (Chechile, R. and Carlisle S., eds) *Environmental Decision Making,* New York,Van Norstrand (1991).

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