MANAGING COMPLEXITY IN DESIGN: THE ROLE OF INTERACTIVE COMPUTER-SUPPORTED METHODS

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ABSTRACT

This paper considers computer-supported design and planning methods in context and presents an evolving conceptual planning process (Structured Planning) as an example of how new methods can reveal structure among information elements previously not perceived as related, so that emerging concepts can be developed more innovatively, holistically and systemically. Since the source of values for decisions in design comes not only from the artifactual world (objective, quantitative data) but also from the world of culture (subjective, qualitative data), the processes discussed are interactive, collaborative methods integrating the best of human insight and cooperation with the best of computer power.

KEYWORDS

Design methodology, computer-supported design process, systems design, structured planning, design technology

INTRODUCTION

As design has affected and altered the environment, problems in our man-made and man-perturbed world have increased in number, size and complexity to the point that thoughtful solutions are now urgently needed in many areas. New strategies are necessary for the design of a wide range of artifacts, institutions, systems and services. These strategies will mandate a high degree of design intervention, but require it to have a degree of sensitivity and insight not always shown in our recent past. In order to help designers to manage the complexities implicit in such intervention, computers must be given a more prominent role than is commonly now assigned. They must be used to support creative planning in the initial phases of concept building.

In the traditional linear model of design, the process flows from analysis to synthesis to evaluation. The conjectural/evaluative, or interactive model, challenges the lockstep relationship of these phases.
In this model, ideas are generated and evaluated as they take form, supporting a co-evolution between problem and solution. The advantages of this format are that ideas are less likely to be lost and that mistakes can be detected earlier. In a large project, this may mean avoiding massive redesign.

Design methodology at the conceptual level has as a mission the creation of innovative concepts, detailed just enough and just well enough formed to be evaluated in terms of their essential qualities and the qualities that they share with other concepts in the overall emerging plan. In the process of producing concepts, the methodology must enable the design team to find ways to combine seemingly independent or even opposing ideas into innovative, complementary solution elements. An effective computer-supported method should also protect the design team from being forced into the position of having to choose among goods. Instead of leading the process toward a choice among candidate designs, it should support a strategy of "having your cake and eating it too", helping the team to find or create that "one more" alternative that integrates the best features of the competing choices, thus avoiding the problem of choice.

Attempts to formalize and model design have a tendency of simplify the real complexity that is inherent in the process. To consider design as a "process of search", instead of an "explorative process", may make it easier to model, but the result doesn't correspond, in fact, to the practical reality of the design process.

This paper will discuss bases for more effective computer-supported methods for conceptual design, using as an example, a system designed for the support of distributed work as it might be performed in a community setting (as opposed to the office buildings of the traditional corporate or institutional setting). The study on work was part of a semester-long project carried out in the Systems and Systematic Design class at the Institute of Design of Illinois Institute of Technology. The methodology used was Structured Planning, a computer-supported planning process developed at the Institute of Design by author Charles Owen [1]. Using tools from the methodology, information is rigorously sought out, structured, and used to synthesize inventive concepts that exhibit systemic properties thoroughly grounded in insightful understanding.
The methodology, now being used commercially, has been used for many projects at the Institute of Design, including a study of Space Station for NASA (1985) and a prize-winning exploration of possible macro-engineering projects to offset global warming

(1990). Teams working with the process have won three awards at the biennial international design competition in Osaka, Japan, including two Grand Prizes.

Progress will also be reported on the development of new tools for the process that employ genetic algorithms as means for evolving and evaluating candidate design concepts.

DEVELOPING COMPUTER-SUPPORTED DESIGN METHODS

Recent accomplishments in computing, especially those concerned with artificial intelligence, have raised expectations for new applications in design, particularly because of the successes of CAD, CAE and other computer-supported techniques for the detailed end of the design spectrum. The thrusts of research now are to find ways to use computers to support the conceptual and early development phases of planning and design. The problems at this end of the spectrum, however, are fundamentally different and, regardless of how they are grounded in design theory, research efforts at this end of the spectrum must deal with a considerably messier part of the design process. Some of the factors to be considered are:

Complexity

The coherence and persistence of any design solution is a function of the interaction among the agents that participate in its design: users, environment, materials, etc. Furthermore, because of the internal complexity of contextual factors -- social, individual, political and economic factors, among others -- a design problem cannot be simply characterized as a problem of optimization, decision making, information processing or pattern recognition. Holland [2] points out that to attempt to study complex adaptive systems (cas) with these techniques is much like trying to play chess by collecting statistics on the way pieces move in the game as opposed to having a cognitive model of how to play the game.

The ability to work effectively in or with a complex system -- as in working with a design problem -- is highly dependent upon the capacity to describe, represent and manipulate information.

The initial step for a useful design methodology, accordingly, should be to support gathering, representing, and generating useful information -- and not to support the creation of artificial systems that learn nobody knows exactly what to produce designs rarely innovative or useful. Artificial intelligence "templates" applied mindlessly will not likely help.

Enhanced Performance Tools

Design is not only about what is quantifiable and measurable; it is also about what cannot be measured, the non-quantifiable.
As the source of values for decisions in design is not only the artifactual world (objective, quantitative data), but also the world of culture (subjective, qualitative data), there are many things that are difficult or impossible to measure adequately.
For instance, what scales or formulations are adequate for judging unhappiness or dissatisfaction? For the support of analysis and decisionmaking in the design process, particularly, there are few tools. Most that are available involve forms of user research, prototyping or computer simulation. New classes of tools will have to be created that deal effectively with qualitative information.

Personal Influences

People accumulate points of view over years of unique experiences, leading them to act with individual difference when assigning weights and values to the many variables inherent in making a decision. Similarly, a critical requirement for one designer will not be critical for another. All aspects of the design process are colored by individual experience. Kant [3] suggested that making judgments about concepts such as utility, goodness, pleasantness or beauty requires understanding the relation between the object and the subject. Because people apply different weights and values, analysis and synthesis are likewise conditioned by individual experience.

To accommodate this as well as benefit from the added richness variety of experience offers, computer-supported design methods must skillfully interweave human interaction with computer power -- human interaction to reveal the variety, computer power to support negotiation. Just as application of decision support systems to the decisionmaking process does not change individual risk profiles (acceptance or avoidance of risks), computer-supported tools will not change individual tendencies toward innovation (incremental or radical innovation). Computer-supported methodologies must seek benefit from human interactions, not avoid them.

The Key is the Concept

In today's competitive and dynamic environment, the effectiveness of a design intervention is deeply dependent on the concept adopted.
For any new product, the question is less how to make it (developing concept to product), than what to make (achieving the concept).

For any area of design endeavor, conceptual design has been demonstrated to be a most powerful factor. Moreover, the way organizations work in the conceptual phases of design is now being seen to have real impact on their future; good concepts are very well rewarded in an open market. Good concepts often seem to be elegant in their simplicity; however, achieving that elegant simplicity is seldom an easy task. Probably the most creative act in the process of achieving conceptual quality is problem finding -- not problem solving.

Conceptual quality in design is heavily dependent on finding and using information, on recognizing insights in that information and transforming insights to testable ideas.

Adaptive Design

Products, systems and services are designed for predetermined uses and users. Almost all are designed and manufactured to be used as they are sold, and to be maintained as they were designed, for their lifetimes. However, this situation, too, is changing.

The trend is toward the incorporation of strategies of adaptivity in designs. For example, a building must be designed to be more flexible in the definition of physical spaces. The designer must know more about how people will change their environments. On the Web, another example, users can determine several fundamental variables such as how the type, images, or colors will appear on their monitor screens. This "Fluid Design" approach is changing the role of the designer as controlling arbiter of all design decisions. Thus, computer-supported methodologies must incorporate strategies for introducing adaptive design features that allow products to be adjusted, updated and rejuvenated to keep pace with change.

AN EXAMPLE

A recent project will provide an example of the state of development of conceptual planning research at the Institute of Design.

The project, The Future of Work: Connecting People and Communities, was conducted in a class in Systems and Systematic Design in which the evolving computer-supported Structured Planning process is applied to complex design problems.

The goal for each project is to develop information meticulously, propose innovative solutions that take maximum advantage of the information, and integrate these ideas into systems concepts that can be evaluated in detail. If approved (in a real situation), these become comprehensive project briefs for the next phase of development, Designing.

DESCRIBING THE PROJECT

Always a substantial part of human activity, work has passed through revolutionary transformations over the centuries, changing significantly in each of its reincarnations. As it is practiced today, however, work practices carry with them damaging social and environmental behaviors -- the abandonment of communities during the day, loss of time with families, increased commuting time, and concomitant environmental pollution from the commuting vehicles. At the place of work, the trend is to smaller and more limited work space, but greater pressure to be efficient. These practices cause severe damage to our work force, our citizenry and our communities, increasing stress and decreasing productivity while diminishing the quality of life.

Charged with suggesting new and innovative forms for work, the design/planning team used Structured Planning methodology as described in the following project phases.

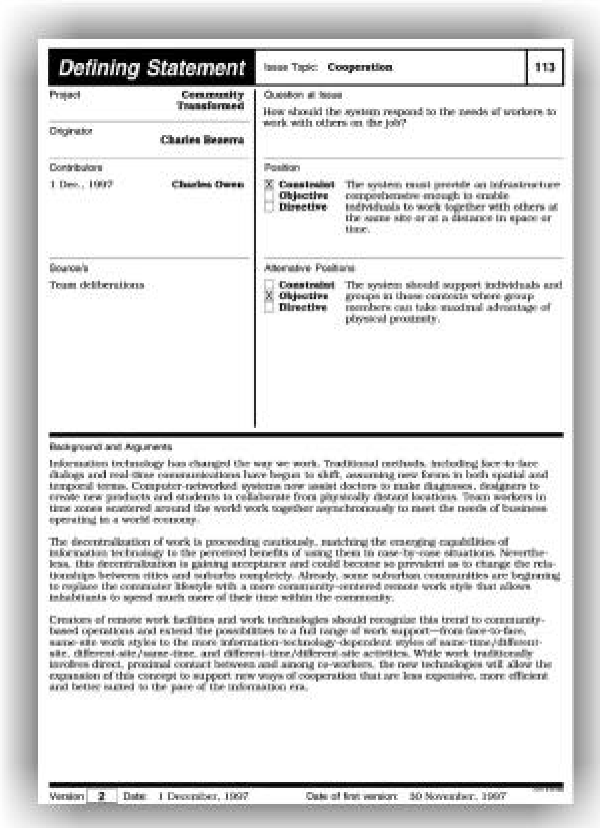
Metaplanning

From an initial project statement, research and discussion was undertaken to understand the context of the problem, establish resources, customize the planning methodology and establish major issues to be considered immediately. The result was a project statement refined from the initial version, a list of issue topics, and a schedule for the planning activity.

Preliminary observation suggested that a major cause of problems is the separation model of living and working. The suburb-downtown separation model evolved to allow workers to live in a safe community closer to nature and free of the dirt and danger of what during the industrial revolution had become very ugly cities. The development of the automobile accelerated the flight to the suburbs, and in the late twentieth century the flight of business and industry from the central city created a new kind of suburb-to-suburb commuter pattern similar to the downtown-to-suburb pattern, but on a grander scale in the ever-growing suburbs and new "edge cities" developing in them.

The consequence of the evolution, now the norm, was the abandonment of dormitory communities by day and the abandonment of downtown and other work centers at night with a vast, twice-daily migration around and between central city, edge cities and dormitory communities. The price for the separation is the inconvenience of living far from work, increased pollution from all the necessary transportation, loss of rural and farm lands to more suburbs, and disconnection of people within their communities. Today, the evolutionary trend is toward knowledge-work, supported by new technologies that enable such work to be performed anywhere at any time. The strategy to be employed in the project was to use these technologies to create a new model of working and living, decreasing stress and related social problems, yet increasing productivity and revitalizing communities.

Project Definition
From the project statement and a list of issues, research focused on the investigation of the issues and the ways that they could be addressed. Arguable positions were taken that became goals for the project -- directions for the planning work to follow. All information was incorporated in Defining Statement documents (Fig. 1). Through them, positions on the issues were expressed, background information presented, and arguments made for the position taken vs. other possible positions.



Defining Statement | Issue Topic: **Cooperation** | **113**

Project: **Community Transformed**

Originator: **Charles Bezerra**

Contributors: 1 Dec., 1997 **Charles Owen**

Source/s: Team deliberations

Question at Issue: How should the system respond to the needs of workers to work with others on the job?

Position: [X] **Constraint** [ ] **Objective** [ ] **Directive** — The system must provide an infrastructure comprehensive enough to enable individuals to work together with others at the same site or at a distance in space or time.

Alternative Positions: [ ] **Constraint** [X] **Objective** [ ] **Directive** — The system should support individuals and groups in those contexts where group members can take maximal advantage of physical proximity.

Background and Arguments

Information technology has changed the way we work. Traditional methods, including face-to-face dialogs and real-time communications have begun to shift, assuming new forms in both spatial and temporal terms. Computer-networked systems now assist doctors to make diagnoses, designers to create new products and students to collaborate from physically distant locations. Team workers in time zones scattered around the world work together asynchronously to meet the needs of business operating in a world economy.

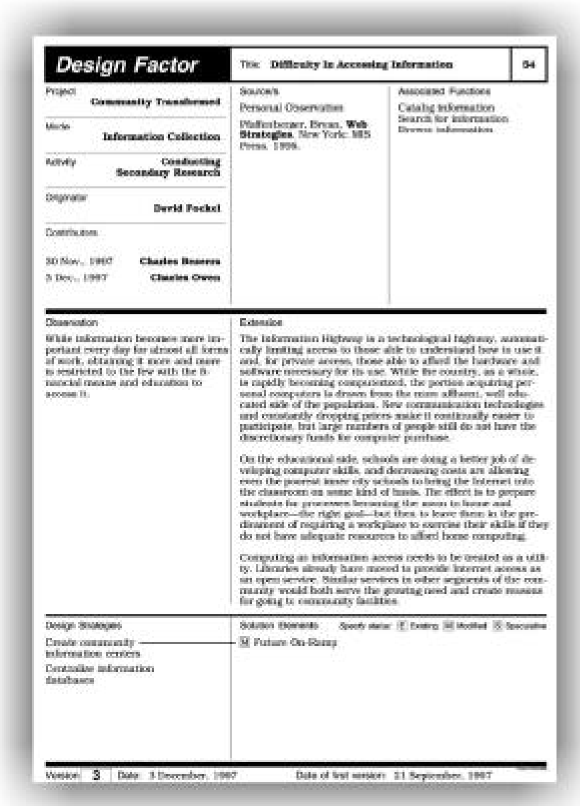
The decentralization of work is proceeding cautiously, matching the emerging capabilities of information technology to the perceived benefits of using them in case-by-case situations. Nevertheless, this decentralization is gaining acceptance and could become so prevalent as to change the relationships between cities and suburbs completely. Already, some suburban communities are beginning to replace the commuter lifestyle with a more community-centered remote work style that allows inhabitants to spend much more of their time within the community.

Creators of remote work facilities and work technologies should recognize this trend to community-based operations and extend the possibilities to a full range of work support—from face-to-face, same-site work styles to the more information-technology-dependent styles of same-time/different-site, different-site/same-time, and different-time/different-site activities. While work traditionally involves direct, proximal contact between and among co-workers, the new technologies will allow the expansion of this concept to support new ways of cooperation that are less expensive, more efficient and better suited to the pace of the information era.

Version **2** Date: 1 December, 1997 Date of first version: 30 November, 1997

Figure 1. Defining Statement document

Information Development
A technique called Action Analysis was employed to uncover Functions (what the system must do), discover Design Factors (insights about the behavior of users and system), and invent Solution Elements (preliminary solution ideas). In this phase, a top-down analysis of the knowledge-working process proceeded from major Modes of operation to Activities and, finally, within the Activities, to the Functions that had to be fulfilled to ensure a good design. The result, a Function Structure, contained at its base level, 86 Functions.
For each, insights were sought for what goes right or wrong in attempting to fulfill its Functions. These insights were separately documented as Design Factors (Fig. 2).



Design Factor | Title: **Difficulty in Accessing Information** | **04**

Project: **Community Transformed**

Mode: **Information Collection**

Activity: **Conducting Secondary Research**

Originator: **David Fockel**

Contributors: 30 Nov., 1997 **Charles Bezerra**; 3 Dec., 1997 **Charles Owen**

Source/s: Personal Observation. Pfaffenberger, Bryan. **Web Strategies.** New York: MIS Press, 1996.

Associated Functions: Catalog information; Search for information; Browse information

Observation: While information becomes more important every day for almost all forms of work, obtaining it more and more is restricted to the few with the financial means and education to access it.

Extension: The Information Highway is a technological highway, automatically limiting access to those able to understand how to use it and, for private access, those able to afford the hardware and software necessary for its use. While the country, as a whole, is rapidly becoming computerized, the portion acquiring personal computers is drawn from the more affluent, well educated side of the population. New communication technologies and constantly dropping prices make it continually easier to participate, but large numbers of people still do not have the discretionary funds for computer purchase.

On the educational side, schools are doing a better job of developing computer skills, and decreasing costs are allowing even the poorest inner city schools to bring the Internet into the classroom on some kind of basis. The effect is to prepare students for processes becoming the norm in home and workplace—the right goal—but then to leave them in the predicament of requiring a workplace to exercise their skills if they do not have adequate resources to afford home computing.

Computing as information access needs to be treated as a utility. Libraries already have moved to provide Internet access as an open service. Similar services in other segments of the community would both serve the growing need and create reasons for going to community facilities.

Design Strategies: Create community information centers; Centralize information databases

Solution Elements (Specify status: E Existing, M Modified, S Speculative): [M] Future On-Ramp

Version **3** Date: 3 December, 1997 Date of first version: 21 September, 1997

Figure 2. Design Factor document

Information Structuring
By reason of their top-down, tree-structured development, the Functions revealed by Action Analysis are not well organized for concept development. The Function Structure form, excellent for analysis, fails as an optimal structure for planning and design because it clusters Functions by derivation, not potential commonality of solution. What is missing is the potential for innovative solution that occurs when seemingly unrelated Functions are recognized to have potential solutions in common that resolve problems for both.

Computer programs RELATN and VTCON were used to reorganize the Functions for concept development. The RELATN program produces a graph in which Functions are linked by their propensity for common fulfillment by solutions. To create the graph, the RELATN program calculated coefficients of interaction based on scores given to all Solution Elements (99 in this case) for their support or obstruction of the 86 Functions. The VTCON program decomposed the graph into clusters of highly linked Functions, then clustered the clusters to build an inclusion structure. The process is hierarchical, its result an Information Structure (Fig. 3) relating those Functions that ought to be considered together. Because the insights of the Design Factors are associated with the Functions, and each Design Factor document includes Solution Elements, the design team can access related problems, insights and preliminary ideas organized to help them to verify final ideas (System Elements) as they are synthesized.

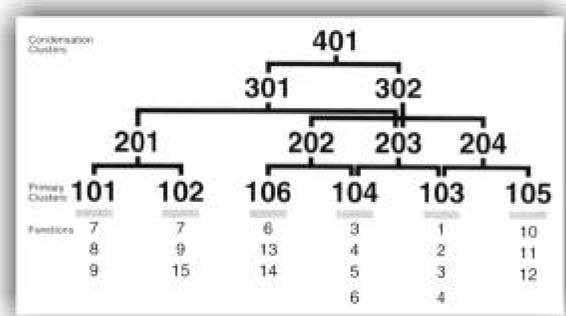


Figure 3. Sample Information Structure produced by VTCON

Concept Development

Working with the Information Structure as guide for ideation and evaluation, the team selected, modified, elaborated or created new concepts to cover the Functions. Using Means/Ends Analysis and Ends/Means Synthesis, the process moved from highly verbal descriptions supported with rough sketches and diagrams to more defined studies and, finally, to formal presentations of ideas as Systems Elements (Figs. 4 and 5) of an overall plan.

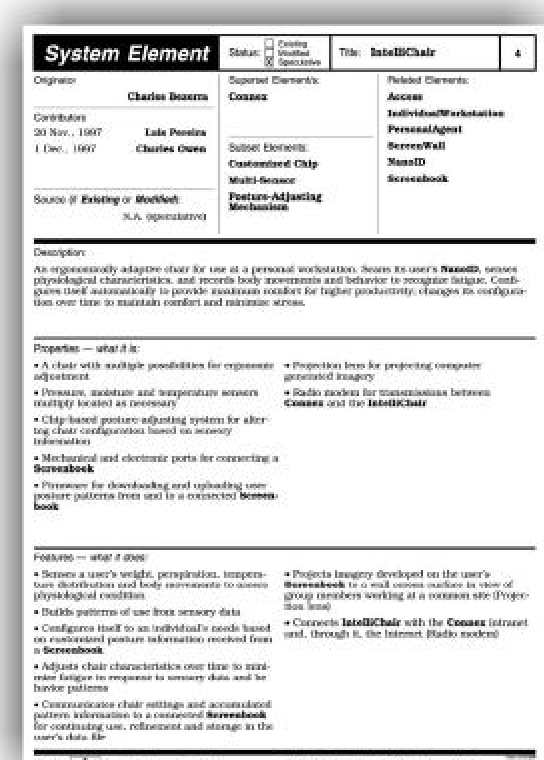


Figure 4. System Element document, page 1

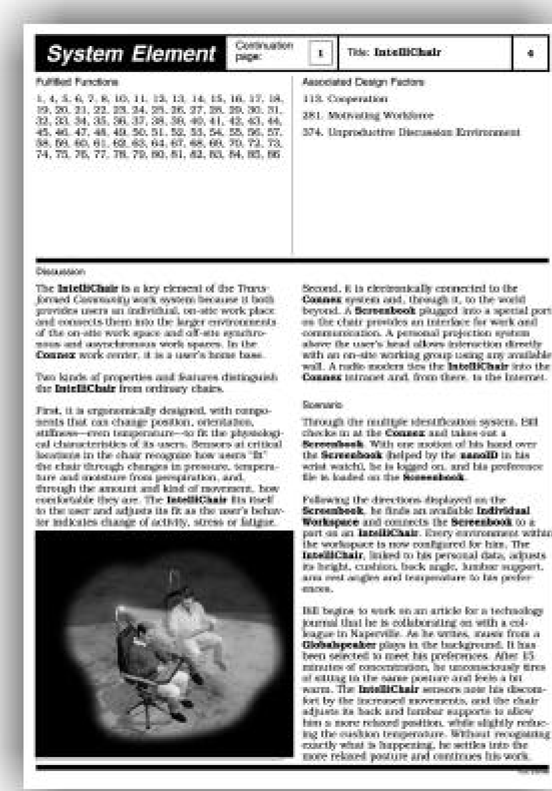


Figure 5. System Element document, page 2

Communication

Finally, a detailed write-up of the Plan and its Systems Elements was augmented with illustrations of important aspects of key ideas.

Illustrations were produced with visualization software that allowed realistic 2-D and 3-D illustrations and animations to be made of important ideas. Pro-Engineer, Alias, PhotoShop and 3dsMAX were among the programs used for this purpose.

CURRENT AND FUTURE RESEARCH

Among research currently taking place in the field is work on a design process based on evolutionary design techniques. The emerging concept, called evolutionary design, is a result of cross-disciplinary research that unites evolutionary biology, computer science and design, Bentley [4].

Evolutionary systems are computer-mediated systems based on an analogy with Darwinian evolution. The concept for them was first introduced by John Holland in 1975 in his book, Adaptation in Natural and Artificial Systems [5]. In the book, Holland describes a new form of adaptive search algorithm today known as the Genetic Algorithm. The Genetic Algorithm is a powerful, adaptive search and optimization technique where characteristics are transmitted from one generation to the next by genes, and where individuals (candidate solutions) evolve under the pressure of a fitness function (objective). The algorithm works using artificial operators of

mutation, crossover and reproduction, much in the manner of natural evolution, Goldberg [6].
As this algorithm, as a process, not only optimize, but also explores all set of possibilities, it can be used for experimentation with the evolution of design solutions, where co-evolution with the problem is possible and an optimal target is unknown. The goal is to explore evolutionary methods for conceptual design, in other words, to use the genetic algorithm as a tool for generation and evaluation in design planning. Two main problems must be overcome.

The first concerns the form of representation for a candidate solution. The problem is how to code and decode a candidate solution so that it can be processed by the genetic operators.
To solve the problem, an adaptation of the Morphological approach has been made by author Bezerra. Morphological analysis/synthesis is a method well known in engineering design, first described by Fritz Zwicky in 1951 [7]. Its use can best be visualized in terms of a morphological chart. A matrix is constructed in which parameters, or variables, of the problem are listed against all possible parameter solutions, or steps. A solution for the problem is formed by a string of partial solutions taken from the list for each parameter. For example, the solution A2, B3, C1 means a solution formed from the second alternative for parameter A, the third for parameter B, and the first for parameter C. At the Institute of Design, research is under way to solve the subsequent problems that are inherent in morphological analysis, such as redundancies, incompatibilities and interdependencies that develop among candidate solutions.
A second, more difficult problem, concerned with how to evaluate candidate alternatives, is the construction and use of a fitness function. To deal with this problem, an interactive method of systematic argumentation (human-computer collaboration) is under study. The plan is to use qualitative and quantitative data from argumentation about prospective solution properties, results of prototyping experiments, trends and expected changes of candidate solutions to score and rank alternatives as well as to produce the fitness function necessary for the evaluation of evolutionary success.
To use evolutionary design techniques with Structured Planning, a chromosome (the string description of a cluster of design-related Functions) will be formed from the Functions that must be fulfilled by the system, the specific Functions determined by their cluster location in the Information Structure. Genes for the chromosome will be formed from potentially acceptable Solution Elements.

Because evolutionary design techniques work on an encoded representation of solutions (the genotype level), they enable rapid generation and evaluation of candidate designs. Without that encoding, techniques that work directly on the candidate designs could only consider a small number of designs, and could not take advantage of the evolutionary analogy.

CONCLUSIONS

This paper has discussed some fundamentals for collaboration between humans and computers in the task of conceptual design. The main goal of these considerations is to improve the quality of the design process and the concepts that it produces. They are based in the conviction that conceptual design is not a closed process, flowing linearly from well-defined problems to solutions, but, rather, a complex, open process where problems and solutions develop together.

Structured Planning methodology was explained as an example of a collaborative, computer-supported methodology, and a system design for the support of distributed work in communities was used to illustrate its application. Structured Planning continues to evolve as a "tool box" methodology for comprehensive conceptual planning.

Current research on the use of genetic algorithms with qualitative information has particular promise for strengthening the synthesis process. As a means for applying evolutionary computation techniques to concept formation, genetic algorithms appear to have much to offer.
Since it is based in human-computer interaction, the approach presented in this paper is quite flexible and appropriate for application to any conceptual problem.

REFERENCES

[1] C. L. Owen, *Design for Integrity,* Institute of Design, Illinois Institute of Technology, Chicago, 1993
[2] J. H. Holland, *Hidden Order: How Adaptation Builds Complexity,* Addison-Wesley, Massachusetts, 1995
[3] I. Kant, *Critique of Judgment,* trans. Werner S. Pluhar, Hackett Publishing, Indianapolis, 1987
[4] P. J. Bentley, A Summary on Evolutionary Design, In *AID '98 1st Workshop Notes on Evolutionary Design,* Lisbon, Portugal, pp. 3-11. 1998
[5] J. H. Holland, *Adaptation in Natural and Artificial Systems,* 4th ed., University of Michigan Press, Massachusetts, 1975
[6] D. E. Goldberg, *Genetic Algorithms in Search Optimization and Machine Learning*, Addison-Wesley, Massachusetts, 1989
[7] F. Zwicky, *Discovery, Invention, Research through the Morphological Approach*, Macmillan, New York, 1969