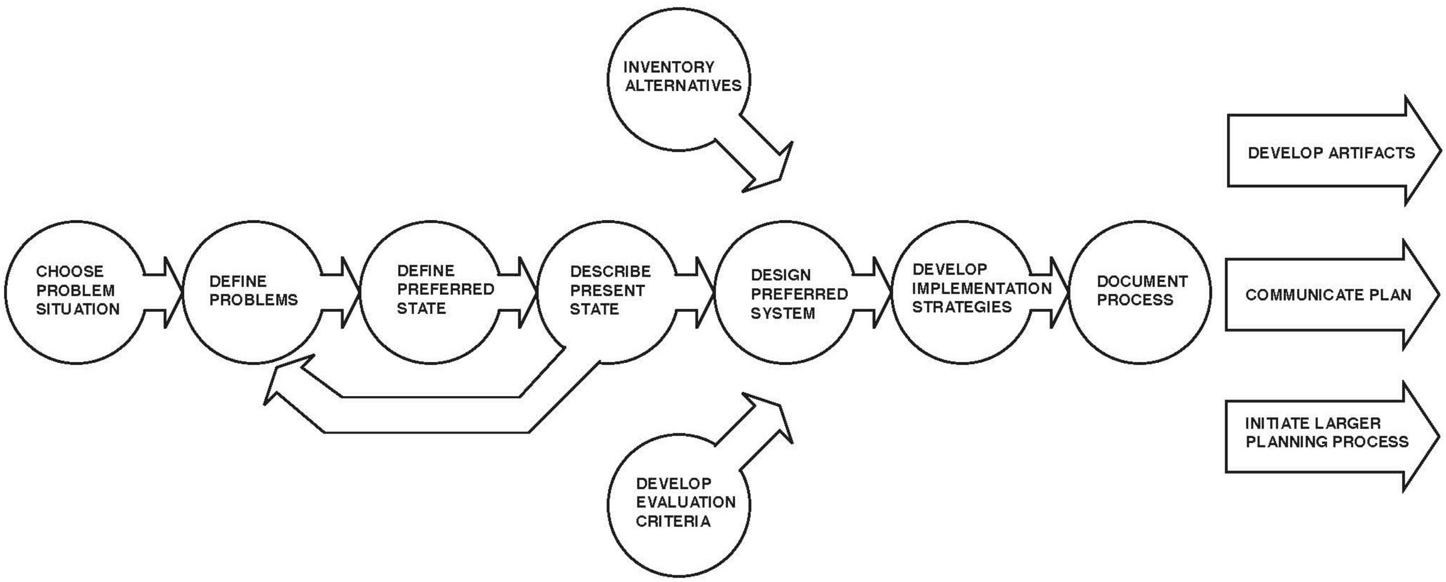
Environmental Design Science Primer



Environmental Design Science Primer

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Origins of Design Science
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Forward

In order to have a significant effect on vital environmental and social issues, people need to acquire the skills that will allow them to act as planners and participants, rather than as spectators in the defining and solving of problems. If environmental education is to be relevant and effective, it needs to balance its approach between activities which alert people to the dangers of a reckless attitude towards the environment, and activities which that inform people how to design and implement positive alternative solutions.

Until recently, concern for the environment has been only a minor factor in the design of the human environment. Even though the environmental sciences have made us increasingly aware of the dangers of unplanned technological growth, trained environmentalists are generally hired by private clients and public agencies to prepare impact statements only after major development projects have been initiated. Not only is this kind of planning far removed from the general public, little understood and often mistrusted, but the environmentalist's input into the whole process is several steps away from actual design and implementation of the project. Consequently, those concerned for the environment are relegated the role of lobbing against new technologies or of becoming involved in legal actions to stop or impede further technological development.

Design science planning offers an alternative. It is a method by which individuals can clarify their own goals about the future, and develop appropriate technological and institutional alternatives to meet them. In this way, others are encouraged to take the initiative in designing better ways to support human needs.

Overview

Humanity on Earth teeters on the threshold of revolution. It has to be success for all or none. If the revolution is a bloody one, humanity is through. The alternative is a design-science revolution.

- Buckminster Fuller

We are presently faced with an accelerating frequency of crises. Reserves of many of our critical resources are dwindling and the Earth's biosphere cannot continue to safely absorb the exponential growth of our wastes. Nearly half of humanity still lives with only minimum levels of life-support and our present methods of planning are inadequate for solving global problems.

The Earth and human society on it are complex systems in which each part is affected by every other part. In the same way that a physician is aware of the danger of treating only a single symptom without considering the rest of the body, planning and design for society must take into account the whole system of which a single problem is only a part. In a complex system like our bodies or the biosphere there is no such thing as a local or specialized problem. Each time we design a solution to a single problem without consideration of the relationships between that problem and the larger context, we only create new problems. We must rapidly come to understand that we cannot deal with problems only on a local or individual basis. Our present inadequate and often careless approach to problems disrupts the delicate interdependent processes of our life-sustaining biosphere. We have not been considering the short and long-range effects of our actions on the Earth system as a whole, even though the biosphere has critical limits of adaptability beyond which there may not be corrective action within our means.

In view of our intensifying crises and our ever-growing capability to seriously affect the environment, decisions which lack a comprehensive and anticipatory perspective become increasingly dangerous. We have entered a crucial transition period in our relationship with our environment; the future of human life on this planet depends on the way we respond to our predicament. A totally new approach is needed to resolve these emerging problems – one that integrates a full range of specialized disciplines and that taps the cultural diversity of humanity.

This primer outlines one alternative to present problem-solving techniques, an approach Buckminster Fuller calls "comprehensive anticipatory design science." Design science is "the effective application of the principles of science to the conscious design of our total environment in order to help make the Earth's finite resources meet the needs of all of humanity without disrupting the ecological processes of the planet."

Comprehensive means dealing with whole systems, the globe, all of humanity and all of the critical variables affecting the problems and needs of Earth and her passengers. **Anticipatory** means preparing for a crisis in advance of its occurrence and acting for both the present and future needs of humanity. **Design** is an integrative process – the synthesizing of parts into a whole. **Science** is the logical, systematic and empirical method of research and ordering of experience.

While preventative medicine attempts to create a healthful environment in which the integrity of the metabolic systems of the human body can be maintained, design science seeks to organize the "external metabolic system" (technological extensions) of humanity to provide life-support services for everyone. It is concerned with whole systems and their environments to ensure health and vitality, and focuses not only on past ills but on future conditions and needs as well.

From his study of our life-support capabilities, Fuller became convinced that all of humanity could be "successful" if we apply our knowledge to finding ways of gaining the greatest possible advantage from the least possible investment of available resources. Each technological process can be measured by its performance. Because know-how can increase when humans experiment with new technologies, performance can be continuously improved. Though there is some material and energy loss with all technological processes, the percentage of waste can be progressively reduced. Design science is concerned with improving the performance of both the components and processes of specific technologies, and the larger systems of which they are a part. It is concerned with applying our evolving know-how to reducing waste and better allowing more people to support themselves.

Design science is not another specialized discipline but rather an integration of disciplines. Its practice is not a further winnowing out of the secrets of the universe, as in research at the frontiers of physics or biology, but an integrative discipline wherein the findings of the sciences and humanities are brought to bear to solve humanity's problems. Design science requires that the traditional separation of the sciences and humanities be abandoned in order to develop a more creative approach to design and planning.

Historically, design science continues in the tradition of the artist-scientist-inventor. Fuller observes:

"Really great artists are scientists, and the really great scientists are artists and both are inventors. I call them artist-scientist-inventors. I think that all humans are born artist-scientist-inventors but that life progressively squelches the individual's drives and capabilities. As a consequence, by the time most humans mature they have lost one, two or all three of those fundamental self-starters. When I speak of an artist or an inventor, I speak of circumstance-pruned specialization. Most of the universally born artist-scientist-inventors have one, two or all three of their innate capability values shut off in childhood. The original artist-scientist-inventor may retain his artist's or his scientist's critical faculties, or only his inventiveness.

World science has come to concede during the last decade that it is now feasible, within the scope of known technology, to support all of humanity at ever higher standards of living than any humans have ever known. In view of that scientific information, I intuit that artist-scientist-inventors who have reached maturity without critical impairment of their original faculties will now become responsible for initiating and industrializing the remainder of technology advancing inventions, for realizing the comprehensive physical and economic success of world man, and that with universal abundance, the warring, official and unofficial, will subside to innocuous magnitude. With that artist-scientist-inventor's accomplishment, humanity may, for the first time in history, come to know the meaning of peace."

Conceptual Tools

A conceptual tool is a concept used for patterning thoughts; it is often a metaphor that organizes information. For example, the metaphor "Spaceship Earth" organizes our perceptions about our environment in an entirely different way than just the word "earth." In the same way that methods are procedures for patterning behavior, the conceptual tool is a method for organizing information, thought and eventually behavior.

The following design science conceptual tools have been found to be effective for organizing our information environment. The design scientist uses them to elucidate relationships among existing information and to help produce new information. These conceptual tools should be viewed as a set of interrelated concepts to be used as a whole.

1. STARTING WITH WHOLE SYSTEMS

The word synergy means the behavior of whole systems unpredicted by the behaviors of the system's parts taken separately. Synergy describes a "law of whole systems" which first began to be understood and accepted by biologists who recognized that no matter how much could be learned about the component molecular structures of a cell, there could be no way to predict life. Similarly, no matter how much is learned about the individual cells that make up an organism, there would be no way of predicting the behavior of a human being. It is true of all systems in nature that each has unique characteristics that cannot be determined only from the isolation and analysis of its components. In thinking about problems, Fuller saw that analysis (the separating out of parts for study) is the basis for all present-day planning and policymaking. It was clear that society had not yet understood the significance of the word synergy. He stated a corollary to this law of whole systems which is a fundamental underpinning of design science: *the known behaviors of the whole system and the known behaviors of some of its parts makes it possible to discover or to predict the behavior of the remainder of the system's parts.* By putting together what is known about the whole with what is known about some of its parts, it is possible to progressively understand more about unknown parts. Since "problems" are parts of larger systems, we can solve a single problem only by understanding its relationship to other problems and to the larger environment.

In order to be comprehensive, any problem-solving endeavor should start with the "whole" and work towards the particular. There are many conceptual "wholes" from which to begin subdividing: the universe, the Earth, all of humanity's problems, all the variables of a particular problem, all of the resources of the Earth. Local problems should be viewed in the context of global problems for two reasons: first so that seemingly unpredictable aspects can be understood by the behavior of the larger system, and second so that local solutions don't create problems elsewhere in the larger system.

2. SYSTEMS AND ENVIRONMENTS

A system is a set of two or more interrelated elements, which can be subdivided into parts. The human body is a system comprised of organs, cells, molecules, atoms, etc. Anything you can describe is a system because anything you can identify is, by nature, composed of a plurality of components. The Earth is a system, you are a system, and I am a system. Everything we can perceive is a system. Because the universe is the largest system we can describe, anything else we define must be a sub-system that divides the universe into two fundamental parts: the system itself and its environment (the rest of the universe).

Environment to each must be
All that is
That isn't me.
And Universe in turn must be
All that isn't me
And me.

-Buckminster Fuller

All systems whether ecosystem, techno systems, or social systems, have an environment into which they fit. Being able to clearly understand relationships between a system and its environment is important because systems are always affected by their environment. The ecologist Howard Odum states this when he says, "the only way to understand a system is to understand the system into which it fits."

3. UNIVERSE

The word universe is the most comprehensive and inclusive term in our language. It is a word we use to describe everything. Albert Einstein, in his theory of relativity, formulated a comprehensive concept of universe by defining it in terms of energy. He said that universe is the aggregate of all non-simultaneous and partially overlapping energy events. Everything, he theorized, is energy, and the total energy is equal to that which exists "associated" as Mass times that disassociating as radiation – $E=MC^2$. This definition takes into account the fact that although the universe is the largest possible system, it is not a single instantaneous event and therefore cannot be unitarily experienced or conceptualized. Fuller became interested in the idea that Einstein's definition describes only the physical universe and does not include Einstein's own thoughts and questions. The theory itself is **not** energy but it certainly is part of the universe. If universe is the most inclusive system we can perceive, Fuller felt it important to have an operational definition which would include both Einstein's description of the physical universe and Einstein's consciousness manifest in his theory. Fuller stated the following definition.

Universe is the aggregate of all humanity's all time consciously apprehended and communicated experiences of the non-simultaneous and partially overlapping energy events.

This means that our universe can be described as the aggregate of our experiences. It is important because Fuller's new definition is not only inclusive, it is understandable and useable in our everyday lives. Because we are inside of our experience, our universe is our experience.

To each of us, our universe is the total of our experience. As we learn, our experience and therefore our universe expands. When we communicate and share experiences, our collective experience expands – ergo: universe is the aggregate of all of our "consciously apprehended and communicated experience." Our collective experience is continuously increasing but always finite, because it is the aggregate of finite experiences (since the experiences of each individual are finite, the experiences of all individuals together must be finite). This view of a finite universe serves as an "operational definition" which can be practically employed. By Fuller's definition, we are integrally part of universe – participants in its evolution – not objective outside observers. The design scientist is an individual who seeks to consciously participate in expanding experience.

> *If we are going to be able to take care of humanity, we must find out how most economically and satisfactorily to organize our environment. Humanity must achieve the success it was designed to be. But we are at the point where there could be a stillbirth.*
>
> *Nothing is so critical as birth, and whether the world survives its birth into an entirely new world and universe relationship depends on our individual integrity, not on that of political representatives.*
>
> *You and I are given hunger so that we will be sure to take on fuel and regenerate our bodies; we are given a drive to procreate so that humankind will be regenerated; we are given brains with which to apprehend, store, and recall information. We are also given minds with which to discover metaphysical principles. The function of mankind is to think, to discover and use principles. We are here to serve as local universe information harvesters and as local universe problem solvers employing human mind's unique access through science to some of the generalized principles governing eternally regenerative universe. We are going to have to exercise this responsibility within decades or perish.*
>
> \- Buckminster Fuller

4. HUMANITY'S FUNCTION IN UNIVERSE

The Law of Conservation of Energy states that energy cannot be created or destroyed; it can only be converted from one form to another. We know that the physical energy universe is in constant transformation and that the two most general characteristics of this process are "entropy" and "syntropy."

The physicist Heinrich Boltzman observed that when energy converts from one form to another or moves from one place to another in a local subsystem of universe, some energy is lost from that subsystem. A process is entropic when a subsystem of universe is transformed from a state of higher order and complexity to a state of lower order and complexity. Conversely, a process is syntropic when a subsystem or set of subsystems is transformed from a state of lower order and complexity to a state of higher order and complexity.

Fuller points out that entropy and syntropy only and always coexist in a finite universe. This means that evolution in a finite but expanding universe is characterized by processes in which energy is being released as entropic radiation as well as being syntropically organized as matter and life. For example, in the sun, atomic structures are being broken down and energies outwardly released. On the Earth, random radiation from the sun is being sorted, collected, and reorganized in new more complex forms. Plants collect the sun's radiation and transform that energy, through photosynthesis, into new molecular structures that in turn become part of even more complex living systems. Animals eat plants and utilize that stored energy to grow more complex structures. Thus the evolution of life seems to be a process of continuously organizing energy. Nothing in nature remains static; systems are always in flux and are therefore either generally evolving (syntropically collecting and organizing themselves) or they are entropically degenerating.

Humanity is part of the evolving syntropic function of universe. If, in light of our expanding effects on the rent of the Earth, we fail to carry out this syntropic function, we become responsible for possible breakdowns of the ecological integrity of the Earth. The design scientist recognizes that constructive change means finding ways of better organizing our matter-energy environment to better support life.

5. GENERALIZED PRINCIPLES

Generalized principles are laws of nature. The word "generalized" means behaviors that hold true in every special case experience.

Humans monitor their environment using their senses and store the collected information in their individual brains. As the number of experiences increase, patterns become apparent which seem to disclose principles common to all these experiences. Science observes and records these "generalized" behaviors that appear to hold true in every special case. When new experience contradicts old observations, principles must either be restated to accommodate this information, or entirely new principles must be formulated.

Newton observed that when objects fall and are pulled toward the center of the Earth, their mass is being attracted to this greater mass of the planet. Further, this attraction could be observed between all objects which have mass. As he experimented, he formulated a principle – the Law of Mass Attraction – that would describe similar behaviors in Nature. Examples of other Generalized Principles are: Synergy, the Second Law of Thermodynamics, and the Law of Conservation of Energy.

Principles (or laws) that have been discovered by science are potentially useful to the design scientist. For example, science's progressive understanding of the laws of aerodynamics and chemistry have been permitted the design of increasingly better air and space craft – from Kitty Hawk to lunar excursion modules. All tools and artifacts are special case reductions of generalized laws of nature. The design scientist consciously employs new scientific breakthroughs and new integrations of scientific information of the law of nature in solving problems.

6. SPACESHIP EARTH

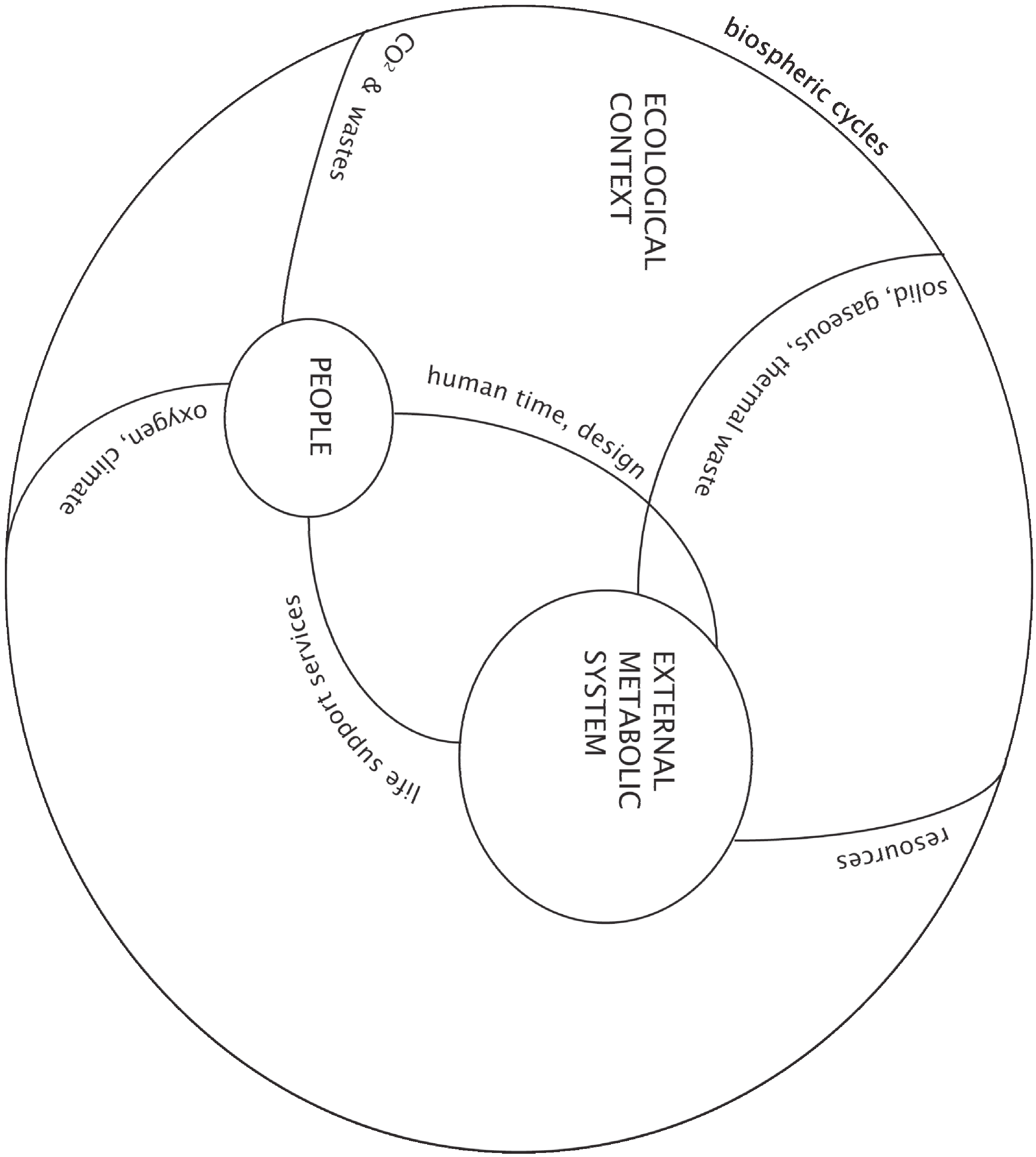
Earth is a small automated, spherical spaceship orbiting rotatively at 66,000 miles per hour around the sun, which in turn is on its own course at 6 kilometers per second within the galactic nebula. With the exceptions of radiation from the sun and the gravitational effects of the moon on oceans and atmosphere, the Earth can be viewed as a relatively closed system.

The conception of Earth as a spaceship helps us to organize our thinking about ourselves. The metaphor can help to make us aware that we are inherently linked to the well-being and effective operation of this tiny ship; like astronauts, we are responsible for the maintenance of the craft that protects and supports our lives.

The idea that humanity is responsible for its action is fundamental to design science. Since Spaceship Earth did not come with an operating manual, our future depends on our ability and willingness to employ our know-how in designing the best possible solutions to the problems that confront us. The design scientist is aware of this responsibility and acts on it. The Earth is a “whole “ from which to begin a systematic design science process.

The following diagram describes the functional relationships between various processes and their interaction with their environment. The outer circle of the diagram represents the ongoing ecological cycles of our biosphere.

The second largest circle represents the various industrial/technological processes that can be broken down for examination. The third circle represents the internal biological metabolic functions of people. The diagram shows how raw materials and energy are extracted from the Ecological Context and converted into useful forms to provide increased life support services for people, (food, shelter, education, etc.). People, in turn, input their energy and intellect into running and improving the external metabolic system. Human waste is either returned directly to the ecological context or to the external metabolic system to be further processed.


ECOLOGICAL CONTEXT
biospheric cycles
CO_2 & wastes
PEOPLE
EXTERNAL METABOLIC SYSTEM
human time, design
solid, gaseous, thermal waste
oxygen, climate
life support services
resources

7. EXTERNAL METABOLIC SYSTEM

Technology is the primary means by which humans provide for their physical needs and adapt to changing environmental conditions. Like other species, human adapt by making internal biological changes over long periods of time in order to accommodate new conditions, but the accelerated use of technology and industrialization in the last two hundred years represents an apparently new manifestation of the evolutionary process.

In addition to adapting by genetic evolution, humans reorganize their environment itself to better support their lives. They take energy and materials from the environment and reorganize them into tools that extend their ability to survive. For example, housing provides an external skin that permits us to function in climates where we otherwise could not survive. Computers store information and do many routine computing functions that free people's minds for other more creative tasks.

We can view our collective technological life-support systems as an external metabolic system that, like our bodies, takes in needed resources, processes them and utilizes them for its maintenance and evolution. Similarly, unutilized wastes from the external metabolic system are passed out into its environment. The external metabolic system functions to serve the various individuals and collective needs of humans just as our internal metabolic systems service the life support needs of the billions of cells which make up our bodies. External metabolics is an organic process and as such provides insight into the continuous interdependence of all the components and processes of our technological and social systems.

The ecological context is the larger system into which the external metabolic system fits. It is the environment to the external metabolic system. "Ecological context" describes the diversity of processes that constitute the Earth's biosphere, other than those that are directly designed and manipulated by man (i.e., hydrogen and carbon cycles, animal migrations, weather patterns, etc.).

The ecological context can be defined as all of nature that is not part of humanity's external metabolic system. The ecological context also includes humanity's own internal metabolic systems as part of the ecosystems of the planet. Humans existed and exchanged materials with the other systems long before the development of society's external metabolic system. Therefore, "people" is included as a subsystem of the ecological context in which humanity as a biological species is studied.

Resources are the food of our external metabolic system. They are taken into the system (inputs) and used to build, repair, and maintain the system as well as produce all the life-supporting goods and services that are utilized by humanity (outputs) such as food, clothing, shelter, education, transportation, communication, recreation, and health care. All of the services and products that support our lives are paid for with resources. We can subdivide resources into several types:

Renewable resources are energy and materials that are continuously replenished by nature at a rate the same as or greater than that of the rate of use. Wood is an example of a renewable resource. Solar energy is an enormous renewable energy source since the external metabolic system presently takes in less than 1/100 of 1% of the solar energy which the Earth receives each day. All biologicals (animals and plants) are renewable or harvestable resources.

These include textiles, forest products, fish and agricultural products.

Even though we have seen that renewable resources by definition are those that can be regenerated by nature at a rate approximating or greater than our use, renewable resources can be depleted through our mismanagement or lack of planning. Perhaps the most dramatic example of this mismanagement of renewable resources is overharvesting of fish in the oceans. There is every reason to believe that a massive, sustained harvest can be yielded by the oceans indefinitely, but only if care is taken to 1) not surpass the critical limit beyond which the rate of reproduction is slower than the harvest and 2) not remove an imbalanced harvest. Removing large quantities of a single species without consideration of the natural food chains and balance of nature in the ocean ecosystem will permanently damage the availability of future supplies. Natural ecosystems are so complex that we may not have the capability to reestablish balances once they are disrupted.

Non-renewable resources are resources that are replenished by nature at such a slow rate that, for all practical purposes, we can assume that when existing reserves are exhausted, there will be no more. Fossil fuels such as coal, oil, and natural gas are examples of non-renewable resources that take hundreds of millions of years to replace. If not properly “melted down” and recycled, primary metals and minerals are also non-renewable, because concentrated reserves in the earth are limited. On non-renewable resources: It is important to understand that with intelligent management and recycling, non-renewable resources can be renewed, and with mismanagement, renewable resources can become non-renewable.

Human resources can be classified in two ways – Labor and Know-How. **Labor** is the time and energy (muscle power) which people invest in the production of goods and services, and **Know-How** is intellect which has been learned from previous experience and which is used to redesign and improve the system. The introduction and widespread use of large mechanical engines and fossil fuels to power them has made human labor dramatically less important as a source of energy. Where once labor was the only direct method of doing needed work, now a single machine can do the work of a thousand men. Automation has further decreased the need for human labor. Yet, as we are becoming obsolete as direct energy sources, the need for the intelligent use of our mindpower is increasing. Design science is a method by which intellect can be reinvested.

Land is also a finite resource that needs to be intelligently planned and managed. As population grows, our need for space to live, recreate, and cultivate grows. Our impacts on the Earth also grow with our expansion, so careful planning to minimize our abuse is essential. The way we use land also affects the way we use other resources. For example, urban sprawl means less land for agriculture or recreation. Food must be transported farther which means more energy is required. More energy is also required because communities use more for personal transportation, heating and other services.

Wastes are the unused by-products of our external metabolic system. What are normally referred to as “wastes” and “pollution” are really valuable resources that are being thrown away because of lack of comprehensive planning and design. Wastes can be found in many forms.

Vast quantities of potentially useable energy are lost from our external metabolic system as **waste heat** that is released and not collected from intense industrial processes for reuse.

Materials are lost and dispersed into the atmosphere in the form of air pollution from smokestacks. They are also released into the Earth's water systems as liquid and solid waste. Human resources are wasted through poverty, malnutrition, bureaucracy, job featherbedding and accidents which prevent this most valuable resource from being re-invested in activities which could more effectively increase our wealth.

Life support represents the products and services that maintain the life needs of people and permit survival and exploration under an increasingly wider range of environmental conditions. Humanity's External Metabolic System exists to produce these products and services. Life support can be generally categorized as:

Food
Shelter
Health and Medical Care
Education
Recreation
Transportation
Communications

8. DOING MORE WITH LESS

Fuller proposed as early as 1936 that human evolution could be charted by our ability to do more with less. He became interested in the idea that our growing understanding of systems in nature increases our ability to get more useful units of life-support for more people with less investment of resources per unit. If our technological systems are a reflection of our understanding of the principles of nature, then waste and inefficiency in our use of resources, disregard for our environment, and neglect of impoverished populations, are reflections of ignorance.

Because we do not learn less, each time resources are employed to do a given task, processes can often be designed or redesigned so that more is accomplished with the same amount of resources. For example, the first telephone wires carried two signals simultaneously. More advances technology enables wires to become thinner and thinner while carrying more and more signals until it became possible for wires to be eliminated altogether. A one-quarter ton communications satellite now outperforms 175,000 tons of transoceanic cable. This principle of "doing more with less" is fundamental to design science problem-solving. The most important aspect of this "more with less" concept is that it offers a way to take care of all of humanity's evolving needs with increasingly less resources per person.

The Earth's resources, which now adequately support 45 to 55% of humanity, need to be employed to support 100% of humanity. The concept of doing "more with less" also furnishes the design scientist with a standard by which strategies and solutions may be evaluated.

9. WEALTH

Wealth is the capacity of a society to deal with present and future contingencies. It is the measurable degree to which we have rearranged our environment so that it is able to support as many lives, for as long as possible, in as many conditions, at a high standard of living. All existing political and economic systems on the Earth assume that the basis of wealth is the accumulation of capital (physical resources) and that there are not enough of these resources to go around. Because traditionally, survival belonged to the "fittest," competition for these scarce resources often degenerated into war. Neither politicians nor scientists have seriously asked the question, "Is it possible to meet the needs of all of humanity without destroying the environment and without any human profiting at the expense of another?" Design science is not concerned with different ways of distributing "not enough." It is concerned with developing new ways of providing enough by doing more with less. This approach brings a new perspective to the debate between economists who advocate continued economic growth in the present manner and environmentalists who recognize the limits of the biosphere and who advocate stopping growth. Neither alternative seems acceptable because each means that there will always be "haves" and "have-nots" in the world or that the Earth might not be able to support life in the future.

Design science assumes that real wealth is generated not by the quantity of resources that can be accumulated, but by the quality of their use. The more intelligently we employ resources, the more wealth they will yield. Fuller has observed that the only thing we have identified in Universe that has no apparent limits for growth is our intellect. Therefore, it is logical that the design scientist assumes that wealth can continuously increase even though the total quantity of physical resources may not. This can occur if we continuously find ways of better and better reinvestment of our know-how to get more with less.

This notion of wealth contradicts the existing economic assumption first stated by Adam Smith that the best way to maximize the total social wealth is for each individual to maximize his/her own. The design scientist is aware of the fundamental interdependence of humans with each other and with their environment. Since intellect is the basis of wealth, humans who suffer brain damage from malnutrition decrease our collective potential wealth because their full intellectual potential is lost to society; "I am better off when you are better off, 'not,' I am better off when you are worse off."

Human time is an important resource which Fuller divides into two groups: **coerced time**, which is the time an individual spends doing those tasks essential to his/her survival (eating, sleeping, getting food, etc.); and **reinvestible time**, which is the time we have free to reinvest in thinking, learning, and designing. The design scientist is concerned with minimizing coerced time and maximizing the total reinvestible time of humans by finding ways of meeting the most essential needs, and by providing effective alternative ways for people to use their reinvestible time. In this respect, the concept of wealth can be used to evaluate the relative merits of design science strategies or other proposed solutions to current problems.

10. TRIMTAB

Trimtab is a word taken from the vocabulary of designers and pilots of aircraft and ships. A Trimtab is a device on the trailing edge of an airplane wing or ship's rudder. It is very small but it is responsible for changing the course of the airplane or ship because it takes advantage of the dynamic principles operating on the vessel by doing the most with least effort. When the Trimtab moves, it creates a low pressure area that pulls the larger rudder to one side, in turn pulling the trailing end of the ship around and changing its course. It is, in effect, the rudder of the rudder.

Trimtab is an important concept in design science. It involves using generalized principles to determine the set of actions that can be taken to change the course of a larger system. In design science, the Trimtab metaphor is used to describe an artifact specifically designed and placed in the environment at such a time and in such a place where its effects would be maximized thereby affecting the most advantageous change with the least resources, time, and energy invested.

11. MAKE VISIBLE THE INVISIBLE

Making the invisible visible is achieved by graphically decelerating events which occur to swiftly to be seen or understood, and/or by accelerating the events which occur too slowly for our perception. The following are methods by which the invisible can be made more visible: **Trending** is a technique for taking resource data, facts and statistics and plotting them through time. This permits the design scientist to perceive patterns of change occurring too rapidly or too slowly to be evident by direct observation. **Hierarchical organizing** is the process of arranging data with respect to its size, shape, form, magnitude, complexity, or any other quality it might possess. **Location/distribution mapping** is a technique for displaying data on maps to demonstrate the shape, size, pattern and/or location of events and their relationship to their environment. This method permits recognition of special relationships that might not be found in charts.

The Dymaxion Map is the most accurate type of flat map that can be used for the display of information. If you consider map projections as a form of objective display you can see that a distorted base for geographical data can lead to distorted or erroneous problem definitions. Buckminster Fuller's Dymaxion Map has two significant virtues that distinguish it from all other maps. First, it is the only flat projection of the Earth's surface that has no visible distortion. In comparison to the commonly used Mercater projection which distorts the Earth's surface by as much as 80%, near the poles, the Dymaxion Projection has less than 2% distortion. This map, when folded along the triangular sections, forms an icosahedronal globe. Second, it is the only projection that shows the Earth's landmass as continuous and connected. It provides a comprehensive picture with only minimal breaks in the continental contours.

12. THE DESIGN INITIATIVE

People concerned with the quality of our environment need to maintain a global perspective while applying the design process to problems in specific local areas. Solutions involve bringing this holistic perspective to bear on one's immediate environment. It is one thing to be able to demonstrate that it is technologically possible to meet the basic physical needs of humanity, but it is another to plan and take actions that will increase the freedom and quality of life for oneself and others.

The ecologist, Aldo Leopold wrote, "ethics is awareness of independence." Design science is also based on the assumption that each individual is better off when every individual is better off, and that it is the responsibility of those who understand this principle to act on it.

A traditional course of action taken by people interested in constructive change is political reform. People organize themselves to convince others of the necessity of change and to elect politicians to carry out those changes, or to encourage political revolution. The design scientist realizes that change is the norm and that nature is continually changing our environment. The important question is not whether changes will have to be made but rather, "when the problems grow more critical, will there be sufficiently developed alternatives to turn to?" For example, the design scientist recognizes that no matter what energy policy politicians adopt, petroleum reserves will only last 20 to 50 years. Design science, rather than lobbying for recognition of this fact, seeks to design practical energy alternatives. The task of the design scientist is to take the initiative and design alternative solutions, to demonstrate the practicality and need for them and to place them in the environment where they can be used.

Our present education system trains individuals with skills in design and the scientific method. Professionals in all fields acquire these skills, then open offices and wait for clients to come to them with jobs. The jobs are tasks that the client wants done in order to further his own interests. Design scientists do not wait for outside clients, or use their skills in this way. The concept of design initiative means that the individual attempts to obtain the most comprehensive perspective possible of human problems, to determine what needs to be done (which no one else is doing), to alleviate these problems and to set out to do it. Taking the design initiative means creating jobs to be done, not filling jobs that don't.

If the design revolution is to excite and interest increasing numbers of people in taking the design initiative it has to be a revolution from the ground up. This means that people have to see how they can learn and participate in designing the environment in which they live. Unless this happens, they will most likely remain inactive until crises make change imperative.

In summary, the task of anyone who is concerned about taking the design initiative is three-fold:

1. To educate oneself to the principles and potentials of environmental change
2. To design specific solutions to problems of the environment, human needs and resources, and
3. To communicate and demonstrate to others the possibilities of organizing the environment in preferred ways.

Bringing about change in the environment does not happen overnight. It is often a long process of many experiments and development efforts over a period of time. It requires many people working on many different levels. The process involves patience, scrutiny, a sense of humor and an overall perspective of the intentions and needs of specific projects. Taking the design initiative is your step. The next part of the primer, the methodology section, is intended to help you take the design initiative. It is a step-by-step guide to the design science process.

FULLER'S FORTY QUESTIONS

Nothing can be more important to an individual's growth than the willingness to ask questions. Not only questions about new experience, but questions which may encourage change in our conditioned way of thinking. Fuller formulated this list of 40 questions that he felt were essential for a comprehensivist to continuously try to answer.

What do we mean by universe?
Has man a function in universe?
What is thinking?
What are experiences?
What are experiments?
What is subjective?

What is objective?
What is apprehension?
What is comprehension?
What is positive? Why?
What is negative? Why?
What is physical?
What is metaphysical?
What is synergy?
What is energy?
What is brain?
What is intellect?
What is science?
What is a system?
What is consciousness?
What is subconsciousness?
What is teleology?
What is automation?
What is a tool?
What is industry?
What is animate?
What is inanimate?
What are metabolics?
What is wealth?
What is intuition?
What are esthetics?
What is harmonic?
What is prosaic?
What are the senses?
What are mathematics?
What is structure?
What is differentiation?
What is integration?
What is integrity?
What is truth?

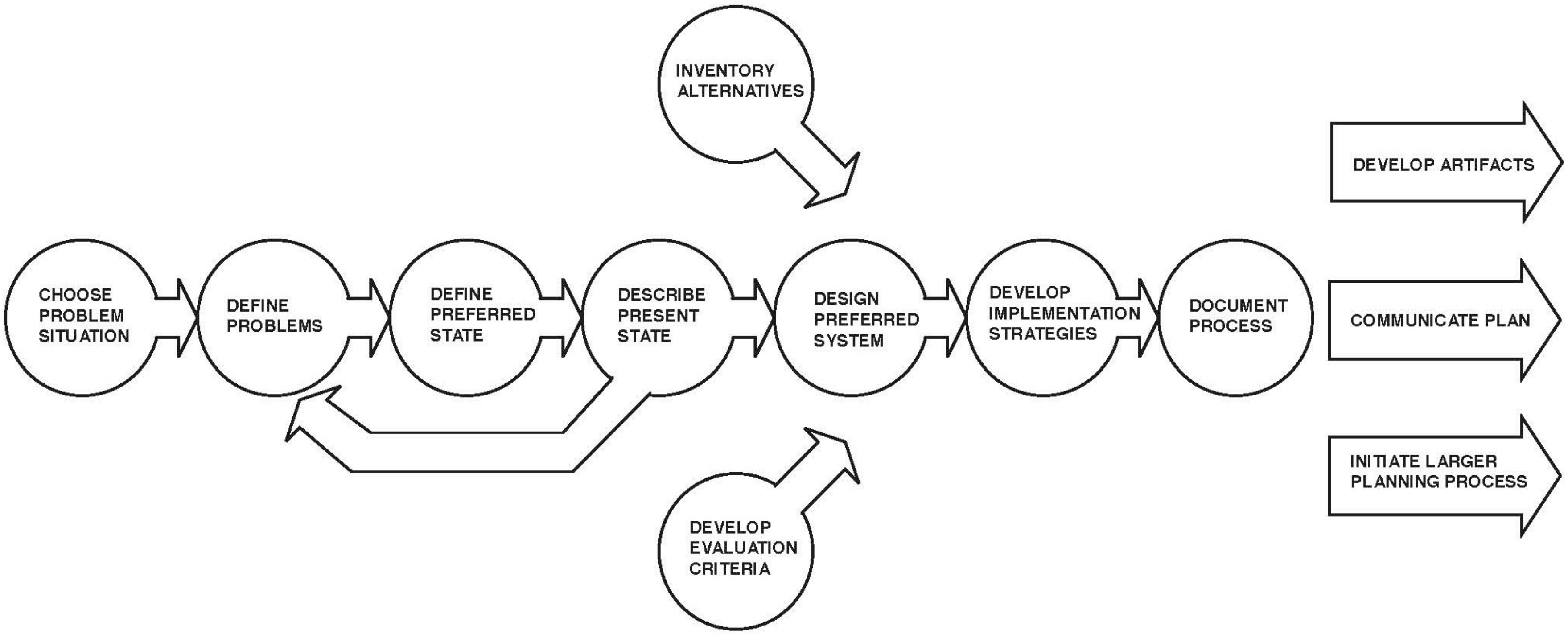
Snowflakes are designs, crystals are designs, music is design, and the electromagnetic spectrum of which the rainbow colors are but one millionth of its range is design; planets, stars, galaxies, and their contained behaviors such as the periodic regularities of the chemical elements are all design accomplishments. If a DNA-RNA genetic code programs the design of roses, elephants, and bees, we will have to ask what intellect designed the DNA-RNA code as well as the atoms and molecules that implement the coded programs.

- Buckminster Fuller

To me the word 'design' can mean either a weightless, metaphysical conception or a physical pattern. I tend to differentiate between design as subjective experience, i.e. designs that affect me and produce involuntary and often unconscious reactions, in contradistinction to the designs that I undertake in response to stimuli. What I elect to do consciously is objective design. When we say there is a design, it indicates than an intellect has organized events into discreet and conceptual interpatternings.

- Buckminster Fuller

Design Science Planning Process



The design science planning process is a method by which individuals or small groups can design alternative paths for themselves and society as a whole. By providing a larger vision of change in which smaller design projects and initiatives can be conceived, a design science plan can become the basis for developing specific artifacts. The following section of the primer is a guide to the steps of this general process for developing alternatives and strategies for environmental and social change.

Methodology

THE DESIGN SCIENCE PLANNING PROCESS

The design science planning process is a method by which individuals or small groups can design alternative paths for themselves and society as a whole. By providing a larger vision of change in which smaller design projects and initiatives can be conceived, a design science plan can become the basis for developing specific artifacts. The following section of the primer is a guide to the steps of this general process for developing alternatives and strategies for environmental and social change.

1. CHOOSE PROBLEM SITUATION

Where do you start?

Often the beginning of one thing is the ending of another. You begin because you want to begin and even though you are embarking on a systematic plan, you certainly will not end up where you think you will because you will change in the process.

The first step of the design science planning process is deciding which directions your group will pursue. You should focus on a problem situation and outline for yourselves an approach to carry you through the entire process. The first task is to choose a situation that needs to be resolved and can adequately be dealt with by your group. The interests, resources, and talents of the participants, as well as the period of time the group will have to work together, should help determine the scope of the project. Be careful not to pick a project too small to challenge you or too large to handle – given the constraints of resources and time.

You don't start out the day with problems all nicely outlined and arranged for you to solve. You start out with a problem situation or to use Russell Ackoff's term – a mess. If you accept given prepackaged problems, you will be starting out with hidden, predetermined assumptions that can interfere with developing a creative response to the real problems contained in the situation. The difference between a mess and a problem is that a mess is something you are aware of in the environment and a problem is something you construct rationally to assist in understanding and effecting change in the environment. Messes are given; problems you define and construct. Problems are your perceptions of why and how a mess is a mess. There are many approaches a design science planning team can take in choosing a problem situation. The following are two that have been used by groups at previous World Game Workshops. The first is to focus on a specific functional area of human life – support needs, such as food or shelter, and to develop a strategy for meeting these needs at a chosen geographical scale (from global to individual dwelling). The second approach is to choose a particular geographical area, such as a neighborhood or national region, and develop a planning strategy for that defined region which includes all of the functional areas of need.

Examples of functional areas of human needs:

Energy
Materials
Food
Shelter
Education
Recreation
Health care
Logistics
Transportation

Communications

Examples of geographic scales for focus:

Individual
Dwelling unit
Neighborhood
Community
City
State region
State
National region
Nation
Global region
Global

If you choose to work with an area of human needs, you define the geographic scale on which you want to focus. If you are planning the development of a specific geographic region, then decide which functional areas, at that level, which you want to consider. It is helpful to remember that, at whatever level you focus, problem solving should move from the general to the specific. In design science, problem recognition starts at the global level and works down to the local level, thus insuring that all subsequent strategies or artifacts developed locally are compatible with global potentials and restraints.

The next step in both approaches is to develop working definitions of the functional area or areas with which you will be dealing. A functional definition describes the designed operation or role that the system under consideration plays in the larger system. Each part of humanity's external metabolic system plays an essential role in the operation of that system just as each part of our internal metabolic system plays an essential role in the operations of our bodies. This role is a specific function that needs to be performed in order for the rest of the system to work properly – to maintain itself and to continue to evolve. The functional definition describes the particular function the area being studied plays in the larger system. It describes what the system does. For example: what do you mean by energy? – The capacity to do work. What role does it perform in the system you are defining? – When considering a transportation system, energy is used to power vehicles.

2. DEFINE THE PROBLEMS

What are the problems?

How do you define what is not working?

There is no such thing as a social, political or economic problem. There are just problems with social, economic and technological components.

- Russell Ackoff

Describing the problem state is the step in the planning process where you define what is wrong. The problem state description should reflect the inadequacies of the present situation and be defined in terms of resolvable factors. For example, if you are considering a transportation system, automobiles could be included as problem factors resolvable by design, but people or political ideologies could not.

Recognizing and defining problems is a difficult and critical task. You are familiar with news reports and analyses of current events in the media. Usually what we call problems are really only symptoms of problems. Symptoms are the visible effects of a problem, while the problems themselves are usually related to the functional or structural characteristics of a system. Distinguishing between symptoms and problems is important in making more accurate definitions of the problems you want to resolve.

The way you describe the problem depends on the lenses you use to see and the yardsticks you use to measure. In this sense, the statement of a problem is not an objective thing but rather a shared expression of what you determine is not working in the system you want to change. It is very common for people to disagree about the nature of a problem because people see situations differently. It is important to discuss these differences and to find common views of the problems involved.

Everyone brings his or her own frames of reference to the design science planning process. These perspectives are based on different political, economic, cultural, psychological, organizational, and religious values and experiences. It is important to understand when and how you use these perspectives and to see the degree to which your own cultural frame of values affects the way you define problems. However useful these frames of reference may be in organizing your ideas of the problem, you must take care to see that they do not inhibit, limit, or predetermine the descriptions that you will develop in the course of stating the problem.

As indicated on the design science planning process diagram at the beginning of this section, you should repeat the problem state description step several times until you are satisfied with your statement of the problems. In the first run through of the problem state step, you will usually generate a list of preliminary questions and statements of the problem. After you have worked through the next two steps, you can return to the problem state step and refine your problem state descriptions. During this refinement, you will often find that different aspects of the problem can be grouped under certain functional categories.

Refined descriptions of the problem state will usually include the following four groups of characteristics.

DISTRIBUTION refers to availability or access. A problem can be described in terms of distribution if everyone is not receiving or does not have access to a particular life-support system. For example, if 50%

of a given population does not have adequate daily food nutrition in spite of sufficient known food supplies in the given region, then it is necessary to make a statement of the problem in terms of distribution.

PERFORMANCE refers to the design characteristics of the system itself. These characteristics are usually described in terms of the system's capacity to produce life-support goods and services with the minimum possible investment of resources and the minimum possible amounts of wastes produced in the process. For example, the U.S. transportation system depends almost entirely on petroleum. A problem statement of this system could describe the performance of each of the different modes in terms of passenger or freight miles per invested resources and the efficiency of each process.

ENVIRONMENTAL IMPACTS are the negative, disruptive effects the present system has on the environment. They are often stated in terms of pollution levels, breakdowns in ecological cycles, environmental diseases, and depletion or damage to environmental resources (biological species, land use, soil quality, minerals, water).

MAINTENANCE AND CHANGE refers to those aspects of the system that regulate and provide channels to change the system. These problem characteristics appear when improper regulation and inflexibility in a system limit its effectiveness in continually providing essential life-support services. If the system cannot be effectively changed by the users to better provide for needs, then this characteristic should be described in the problem state. For example, if a region depends entirely on natural gas for heating and there are no mechanisms for people to convert their heating systems to another source of energy, then when the supplies of natural gas are exhausted, they will be unable to heat their buildings.

The following is an example of the problem state described in the 1974 World Game Workshop energy strategy:

The main impediments to evolution in the present energy state have brought about a situation in which there is:

Not enough energy available for 100% of humanity's life-support, e.g., forced fuel rationing, materials shortages, forced shorter workweeks, "blackouts," "brownouts," etc. in developed countries, and little or no industrial energy available to construct and develop tools for life-support in developing countries.

Inequitable distribution of energy consumption; for example, the United States, with 7% of the world's population, consumes 32% of the world's energy.

Low efficiency of energy conversion, such as appliances that waste electricity, cars that consume too much fuel, materials that require a lot of energy used in place of low-energy-costing materials, uninsulated structures, etc. Present-day energy converters average 4-5% over-all thermal and mechanical efficiency. For every 100 barrels of oil produced, 95 go down the drain. An overall efficiency of at least 12-20% is feasible with present-day design and engineering know-how.

High negative environmental impact of energy inputs and outputs of the external metabolic system; e.g. resource depletion, waste, pollution of air, water and land by unwanted chemicals, heat, artifacts, and noise; and disruption of ecological cycles through strip mining, pipelines, etc. In short, an environment whose capacity to provide what we are demanding of it, and to absorb what we are injecting into it, is rapidly becoming insufficient.

High use of short supply energy resources, such as fossil and nuclear fuels.

Low diversity/redundancy of energy sources and systems; e.g., most of our "eggs" are in one basket: oil.

High use of coerced human physical labor input.

Centralized and one-way energy systems; i.e. energy flows from monopolistic utilities and corporations to individual consumers, without the inverse option.

If our local gas station, the sun, ran out of supporting energy, the next closest refueling star is 25 trillion miles away.

- Buckminster Fuller

The new social movements for peace, a humane world order, social justice and ecological sanity are now determined to get in on defining the questions. That's what public participation is all about. Citizens now understand that professionals with narrow, specialist training in the sterile, quantitative methods that women, luckily, often escaped, cannot adequately define our problems. Not that professionals are not essential to the debate, but that they must now be able to see where the limits of their technical competence end, and where their values carry no more weight than those of any other citizen in a democracy.

- Hazel Henderson

GROUP METHODS

BRAINSTORMING is a group method for generating ideas. You can use brainstorming in the problem state step to produce many views of the problem. First determine a period of time the activity will last; usually 10 to 15 minutes is sufficient. Next, define the subject of the brainstorm and ask all of the participants to offer different ideas or views of the problems. Have a member of the group quickly list the ideas on the blackboard as they are suggested with modification or arranging. The important role of brainstorming is that it allows a diverse and wide-ranging set of responses to be generated without judgment. Brainstorming is not analytic and imposes no constraints on the listing of possible ideas.

GROUP CONSENSUS is a method of reducing the many views generated by a group to a minimum number of agreed upon statements. First ask all of the participants to list what they think are the most important characteristics of the problem state. Next, compile these lists and make a master list of all of the responses on the board. Then discuss the appropriateness and priority of each statement. Next, as a group, decide on the most important and articulate statements.

SIMULATION GAMING is another means to gain an understanding of a situation. It is a method of experimenting with new perspectives to imagined or real circumstances which may or may not be similar to your own. You play by imagining that you are in a new role and faced with a particular situation. How will you respond?

The Spaceship Captain Game is a simulation game that has been used at World Game Workshops. The participants imagine that they are the captain of a spaceship that is in trouble. They do not know what is wrong. The participants are asked, *what do you need to know in order to identify the problems and insure the ship's survival?* The responses, in the form of questions are listed on the board. This game is very useful when learning to recognize and define problems. It helps to determine what kinds of information are necessary for general problem solving.

The following are sample responses generated by this game:

How do we know there is a problem?
What are the problems?
How critical are they?
Where do we find them?
How many people do they affect and to what degree?
What resources are available to solve the problems?
Have these problems happened before?
How successful were past solutions?
What are the alternative solutions?
How would we evaluate the proposed solution?

QUESTIONS/EXERCISES

1. What is a problem?
2. What is the difference between a symptom and a problem?
3. What is a frame of reference/?
4. What are your frames of reference?
5. Ask the people in your group to define the world food problem.
6. What are their hidden frames of reference?

3. DEFINE THE PREFERRED STATE

What do you want?

Where do you want to go?

How should the systems work?

The preferred state is the step in which you state your goals. It is the translation of your values into a description of an ideal situation. The preferred state is your definition of success and therefore will be the inverse of the problem state. Outlined as a set of objectives, the preferred state represents your idea of the desired functioning of the system for which you are going to plan.

To describe the preferred state, suspend all constraints except for those of technological feasibility and maintaining ecological integrity, and answer the question *what would an ideal future look like?*

Defining a preferred state can be a simple brainstorming game for your group. In most cases, this step in the planning process can be conducted entirely verbally. Extensive research and technical analysis are unnecessary for determining what you want. As Russell Ackoff has stated, "there are no experts for what should be." Everyone has an equal right to contribute and help form the goals in the planning process.

Defining the preferred state forces you to make explicit **what you want** and **where you want to go.** This step involves developing a working hypothesis which you will test and document as you develop a complete strategy. For example, if your preferred state includes providing adequate nutrition for every human on Earth, the plan you develop then becomes an experiment to test if the goal is possible and how it might be brought about.

Another way of viewing the preferred state is to see it as a frame of reference to the present situation. This provides a perspective from which to view the difference between **what is happening** and **what should be happening.** A physician diagnoses a patient on knowledge of a "healthy" or preferred state functioning of the body. Problems can be better understood by referencing them against as clear as possible a notion of how the system should be working. Though humans have rarely attempted to define a preferred state for society and used this as a tool for understanding and resolving our problems it is essential in order to plan for the future.

The design team often develops a preferred state by first generating a set of general values shared by the group and then comparing them to a set of values that are known to be operative in the problem state. From these preferred values you can develop an outline of those preferred characteristics of the system you are planning. For example, if you value conservation of material resources as opposed to excessive waste of resources, the description of your preferred state would reflect that value: e.g. packaging should be designed in such a way that it can either be reused or readily recycled.

The following is an example from the 1975 World Game Workshop's Regenerative Resource Economy Group of a comparison between preferred values and problem state values:

Harmony with nature...man vs. nature
All of humanity...part of humanity
Concern for degradation of the environment...limited awareness and interest in the environment

Humanitarian...elitist
Livingry...weaponry
Global perspective...national perspective
Interdependence...independence
Societal interest...self interest
Cultural diversity...cultural homogeneity
Systemic thinking...reductionist thinking
Cooperation...competition

The groupings of characteristics used in the problem state can also be used to describe preferred characteristics.

DISTRIBUTION. Describe the preferred availability of any life-support service that the system under consideration is intended to produce. Since providing adequate life-support for all humanity is the general goal of design science, considering thee distribution of a service or product is very important.

PERFORMANCE. Consider the design of the system in terms of its capacity to produce life-support goods and services with the minimum possible investment of resources and the minimum amounts of waste produced in the process.

ENVIRONMENTAL IMPACTS. Consider the environmental impacts of the preferred state. To minimize negative or disruptive effects on the environment, this step must be carefully described. Designing with nature is fundamental to design science because it is the only way we can assure our continued health.

MAINTENANCE AND CHANGE. Describe your idea of how the system is to be managed and regulated and how future changes in the design can be initiated and implemented. This is very important in relation to the popular acceptance and long-term survivability of the system.

The following is an example of a preferred state description excerpted from the 1975 World Game Workshop food strategy.

Given the present global food problems, a preferred state would be one in which sufficient nutritionally sound food for all of humanity's healthful survival and evolution is available on a regenerative, non-depleting basis.

- A global food system should allow for maximum individual flexibility in food types to permit as much cultural diversity as possible.
- Food should be a birthright, not an economic weapon of exploitation.
- The food system, as well as the food, should be safe. For example, farm workers as well as food should not be exposed to dangerous pesticides.
- There should be little coerced human labor involved in the food system as possible.
- The global food system should be regenerative; that is, it should not be based on resources which are rapidly being depleted such as fossil fuels and it should not be based on short-sighted practices such as poor soil management.
- It should have the least possible negative environmental impacts and the most possible impact as possible, such as the build-up of poor soils into rich soils.
- There should be an optimum diversity of food crops and a diversity of different strains within each crop. There should be an overall genetic bank increase.
- There should be a minimal dependence on adverse fluctuations in the natural cycle.
- The global food system should operate at maximum efficiency – in terms of energy, materials, land and human time use in all stages of the food system.
- There should be a built-in flexibility in the system; there should be a back-up storage

system to insure the maximum amount of nutritionally sound forward days for all of humanity.

- The fear of an inadequate food supply should be vanquished. Planning and management of the global system should be as comprehensive and anticipatory as possible to insure a regenerative supply of food for everyone.
- A global food system should also have a high amount of monitoring and feedback for quality and quantity control.
- Access to all accurate food information should be as high as possible.
- There should be a maximum amount of research and development related to improving the food system.

Your descriptions of a preferred state will naturally change and evolve as you explore further new ways of seeing problems and developing possibilities. As your personal values change, your preferred state descriptions will change. It is often useful to repeat this step over again in order to clarify the common objectives of the planning team.

QUESTIONS/EXERCISES

1. What are values?
2. What are your values?
3. What is a goal? An objective?
4. Ask your group what is their preferred state for a transportation system in the United States.
5. Compare the different values and goals implicit in the responses.

4. DESCRIBE THE PRESENT STATE

How can you describe the present state?

How is the present system operating?

What do you need to know?

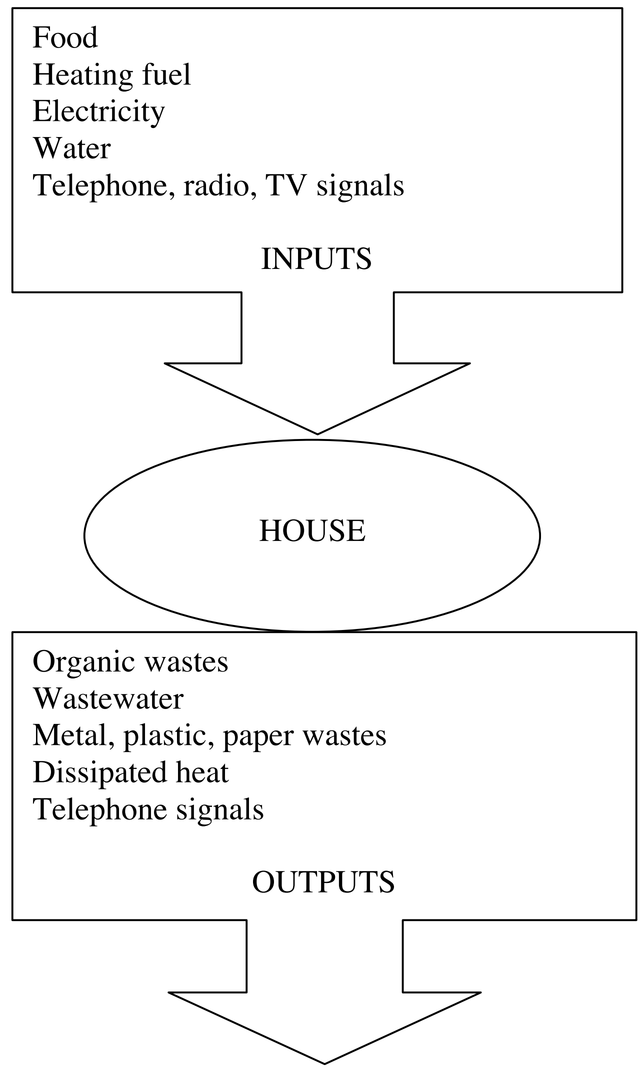
In describing the present state, you attempt to gain a comprehensive picture – a many-faceted analysis of the present situation. The purpose of this step is to clarify critical factors of the problem that will permit you to organize data about the system under consideration. The present state is the environment in which the problem is defined and out of which the preferred system will be designed.

Every present state requires a slightly different set of descriptive tools. Sometimes it is necessary to invent new ways of describing aspects of the system in order to understand adequately what is going on.

The following set of tools, used by previous design science teams, were developed out of a need to answer the question: *What types of information are needed in order to make the most intelligent decisions about the system being considered?* A more detailed explanation of these tools is located at the end of this planning methodology section.

AN INPUT/OUTPUT ANALYSIS is a chart or diagram that shows the inputs and outputs of a system. You can make an input/output diagram by outlining a system and listing what goes in and what comes out.

COMPONENTS AND PROCESSES are diagrams that show how the different parts and processes of a system are related. Your body is made up of different organs which function in different processes: e.g. the lungs are part of the respiratory system; the stomach is part of the digestive system. You can make a components and processes diagram by graphically representing the system and indicating the components and processes involved.



KEY INDICATORS are specific measurements that indicate the state of the system being examined. Temperature and blood pressure are key indicators of an individual's health. Passenger miles, available edible protein, energy consumption, population growth rate, unemployment rates, inflation rates, efficiency ratings of tools are all examples of key indicators of different social and technological systems. You can invent new key indicators by measuring characteristics of a system that you think provide an indication of its relative health or performance.

TRENDS OF KEY INDICATORS are charts or displays showing changes of key indicator measurements over periods of time. You can make a trend by plotting key indicators or other quantified data over a time line.

TRENDS MOST LIKELY TO CONTINUE are trends which available evidence indicates are going to continue to follow a specific pattern or direction. For example, if evidence suggests that population growth will continue to increase during the next twenty years, list that trend and suggest the causes and consequences.

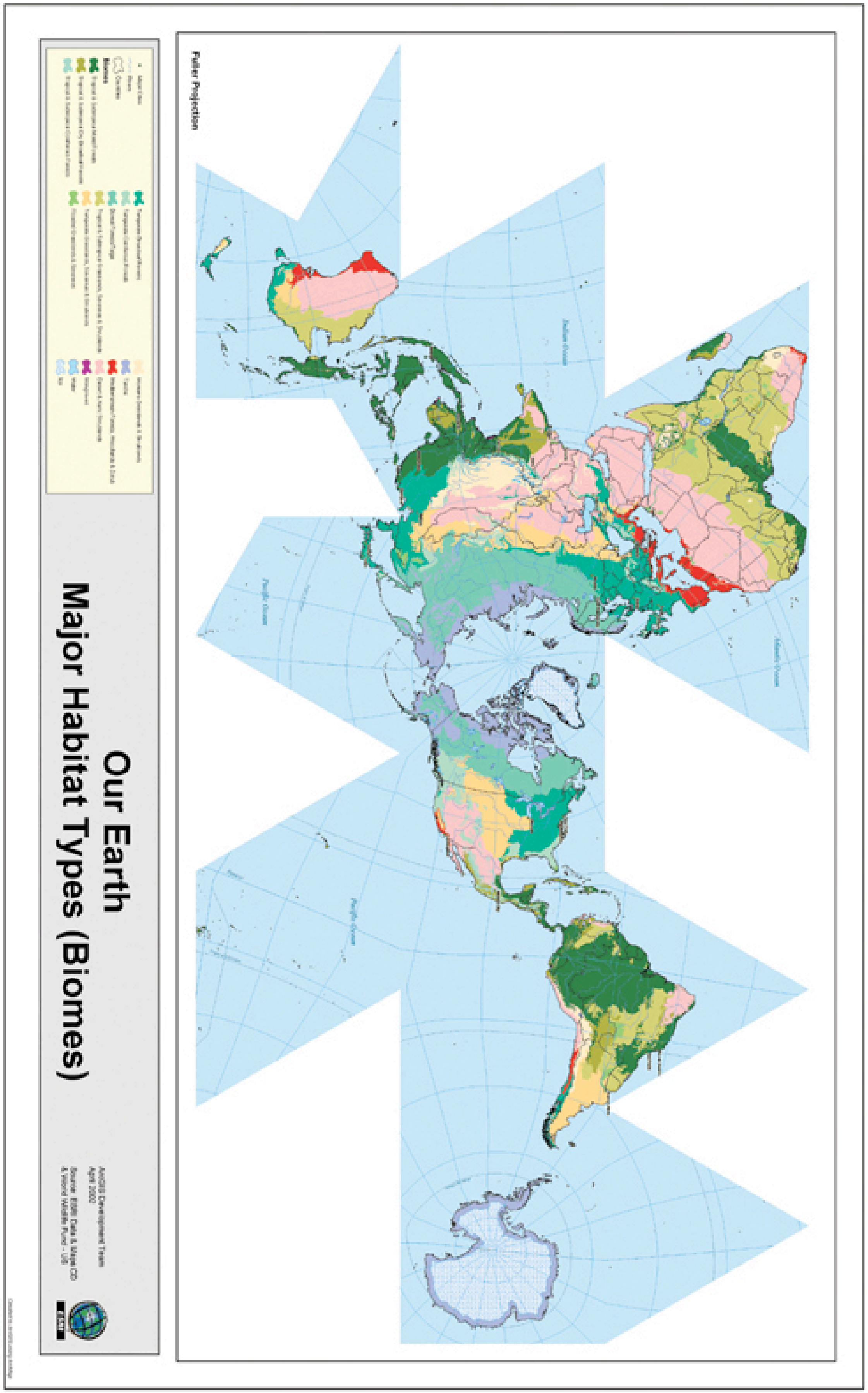
INTERACTIONS WITH OTHER AREAS (CROSS-IMPACT ANALYSIS) is a method of analyzing the interactions of different sub-systems or systems. The analysis is made by constructing a two dimensional matrix with the different systems entered along both dimensions. For example, if you wanted to show the interactions between an energy system and a transportation system, you could construct a matrix with both systems indicated along both dimensions. You can quantify the matrix by showing how much energy is used by the transportation system, how much transportation is use by the energy system, how much energy is used by the energy system, and how much transportation is used by the transportation system.

If you want to know the cross-impacts of an additional system such as communications or if you want to divide transportation into different subsystems, just list those additions along both dimensions and fill in the new matrix. The quantities you use are your choice and will depend on the types of interactions you want to show. For example, you could use dollars to show money interactions or Kilowatt-hours to show interactions in terms of energy measurement. The interaction matrix can also be used to simply catalogue the interrelationships of different systems, e.g. trucks transport gasoline and gasoline is used to fuel trucks.

NET ENERGY ANALYSIS is a type of input/output analysis used in analyzing different energy sources and conversion systems. Net energy is the energy that is left over after the energy costs of getting and concentrating the energy are subtracted from the original gross energy. **Gross Energy** (output) minus **Energy Costs** (input) equals **Net Energy** output. High net energy sources have higher economic potential than low or no net energy sources.

AN INVENTION CHART is a chronological inventory of inventions related to a particular area such as shelter or transportation. To make an inventions chart, list in order of appearance (by year) inventions or artifacts that influenced the development of your system.

LOCATION AND DISTRIBUTION MAPPING is a method of displaying specific data about technology, environmental resources, and human needs on maps. The quantified data to be displayed can be subdivided into specific ranges of type, quality, or rate: for example, ecosystem type (tropical rain forest, desert), number of beef cattle (1 to 5, 6 to 10, etc.) or population growth rate (1% to 2%, 2% to 3%, etc.). These ranges are then graphically indicated and correlated to the geographic area to which the data refers. The following is an example of location and distribution mapping of biomes (bioregions) on a Dymaxion Map.


Our Earth
Major Habitat Types (Biomes)
Fuller Projection
ArcGIS Development Team
April 2002
Source: ESRI Data & Maps CD
& World Wildlife Fund - US

AN INFORMATION SYSTEM is a tool for filing and storing information that is researched and collected for use in a design science plan or strategy. There are many different ways you can store and file data.

The following three tools are included in the information system and are helpful in both the progress of your work and in documenting your work when it is completed.

GLOSSARY is a listing and definition of terms important for understanding the system you are planning.

RESEARCHERS, AUTHORITIES, AND ORGANIZATIONS is a listing of 1) individuals and institutions presently engaged in research and development, and 2) people to contact for feedback or advice in your work, and 3) organizations which influence decisions in different areas related to your system.

BIBLIOGRAPHY/REFERENCE is a listing of books, journals, articles, and other information sources dealing with the system.

GROUP METHODS

DATA ACQUISITION GAME is a method of learning where to find sources of various data. Ask a series of questions such as: How many bicycles are there in Australia? How much milk is consumed in Mexico? Where do date palm trees grow? Then, brainstorm what information sources you would use to find the answers. Test the different sources and determine which ones lead to the answer most readily. After playing this game many times, it is possible to develop a list of the best sources of data (or sources of sources of data) for use in design science research.

QUESTIONS/EXERCISES

1. Where will you find data for your problem area? How will you organize it?
2. What is an analysis?
3. What is a display method?
4. Make an input/output diagram of your house and quantify it.
5. Make a components and processes chart of your house.
6. Make a trend chart showing the number of miles you have traveled per year over the past ten years.

5. INVENTORY ALTERNATIVES

What choices do you have to select from?
When you are making a plan and you have seen where you are and where you want to go, you need to identify all the known alternatives for getting to the goal. It is important that this list be comprehensive so that the range of choices made reflect the best options available.

You need to have certain information about each alternative so that you will be able to know how and where each can be used. You should know how they work and the particular situation to which each is best suited. Here is a sample form with characteristics of what you might need to know about each.

ALTERNATIVES CHECK LIST

1. Explanation of Process (include diagrams if possible): How does it work?
2. History of Prototypes: Uses, development, etc.
3. Capability of Alternative: What can it produce? What scale can it be operable on?
4. Environmental Conditions: Conditions necessary for operation (i.e. wind speed, sunshine hours, running water, etc.)
5. Resources Utilized: What is it made of? What do you need to build or install it?
6. What are the best uses? Applications?
7. What kinds of personnel are needed?
8. How is it managed, regulated, and changed?
9. Advantages (benefits): What are the positive impacts – social, economic, ecological?
10. Disadvantages (costs): What are the negative impacts – social, economic, ecological?

The availability of alternatives reflects the degree of our freedom of choices. No freedom of choice can exist where there are no alternatives. The more alternatives a system has, the more viable that system will be. Inventorying existing alternatives and developing new ones is a critical need of society and the task of the design scientist.

In any situation, the limited availability of alternatives threatens the survival of the system. If an electrical circuit has only one pathway for electricity to flow and the wire is broken (the pathway interrupted), the system ceases to function. In an urban electrical grid, there is redundance. This means that if one cable breaks, there are other paths for electricity to flow so that the whole system does not shut down.

Living systems are able to grow in a changing environment because they are enormously complex, having many alternative pathways for achieving any one goal. Humans are the most complex and adaptable systems we have discovered in nature; for example, it has been estimated by biologists that there are 30,000 pathways for information to flow between any two neurons in our brains. That permits many alternative paths for a signal to move along. We need to employ this principle of redundancy in the design of a preferred system. Alternatives make possible different pathways for achieving the same or similar goals.

QUESTIONS/EXERCISES

1. What is an alternative? An inventory?
2. What characteristics will you include in your inventory?
3. Where will you find data to do your inventory?
4. Inventory all of the possible methods you could use to conserve energy in your home.

6. DEVELOP EVALUATION CRITERIA

How do you choose the best alternatives?

After all alternatives are inventoried, the next step is to develop a set of evaluation criteria by which various characteristics of each alternative can be assessed. After each is evaluated, the best alternatives can then be selected for your plan.

Evaluation criteria are the guidelines for reaching a preferred state. They represent our values and priorities and thus reflect what we think is important in making decisions about the design, implementation, use and maintenance of systems. Evaluation criteria can be general guidelines for decision makers or they can be performance specifications for the designer. The criteria are developed by formalizing the set of values articulated in the preferred state. They can first be described qualitatively (general criteria) and then they can be more specifically defined in terms of quantitative measurements (more specific criteria). For example, a general criterion for the selection of a transportation system alternative could be that only minimum gaseous hydrocarbon or nitrous oxide pollution be permitted. A specific criterion, on the other hand, could indicate the specific amounts of those compounds that are to be permitted. Another general criterion could be that the alternative must convert or use only renewable income energy sources. A specific criterion could specify the range of energy conversion efficiencies necessary for the design of an alternative transportation vehicle.

Our biosphere is a set of delicately balanced, interrelated eco-systems that are inherently interdependent. When one part of these systems is disrupted, the whole system can be damaged. For example, destruction of a link in a food chain because of local pollution could cause extinction of a species several steps down the food chain.

Pollution control standards are evaluation criteria developed to minimize negative environmental impacts of human technology. Since these standards are criteria to measure undesirable substances dispersed in the eco-system, much care has to be taken in determining what are safe levels, in both the short and long-term perspective. Ideally, the systems you design should have pollution outputs as close to zero as possible.

Evaluation criteria reflect the values and priorities of those who create them. In recent years, for example, considerable public debate has been focused on what our pollution standards should be. The mandate for the future seems clear, accept rising levels of harmful pollutants or redesign the technological systems. Using pollution as criteria for system evaluation allows us to state our values and measure how far we are from the desired goal of minimum pollution.

The following are general evaluation criteria that were used by the World Game Workshop energy team:

ENERGY CRITERIA

- Maximum value placed on doing the most with the least amount of energy
- Minimum use of energy-intensive materials
- Maximum use of reusable materials and packaging
- Minimum energy use in construction, maintenance, and recycling
- Minimum dependence on one source of energy
- Maximum diversification and interdependence of energy sources

- Maximum availability and distribution of power
- Maximum value placed on user's time and energy
- Maximum comprehensive responsibility and responsiveness to the needs of energy users by energy suppliers

SAFETY CRITERIA

- Maximum value placed on human life
- Maximum safety in construction, operation, maintenance, and recycling
- Maximum designed-in safety for emergencies and breakdowns
- Maximum safety for future generations

ADAPTABILITY CRITERIA

- Maximum value placed on adaptive stability
- Maximum responsiveness to short-term energy demand changes
- Maximum expandability/contractibility (responsiveness to long-term energy demand changes)
- Maximum reserves of emergency supplies and facilities
- Maximum flexibility and adaptability to new technology, needs, and know-how

EFFICIENCY CRITERIA

- Maximum value placed on doing more with less
- Maximum use of minimum numbers of energy artifacts, systems, and services
- Maximum energy output per invested man-hours, materials, and energy input
- Maximum ease, simplicity, and clarity of repair, replacement, and recycling in minimal time
- Maximum use of modularity of construction where applicable
- Maximum concentration of energy-intensive activities
- Maximum interlinkages of energy-intensive activities
- Maximum use of low impact decentralized energy-harnessing artifacts
- Maximum energy conversion and transport efficiency use
- Minimum heat discharge into environment

ECOLOGICAL CONTEXT CRITERIA

- Maximum value placed on virgin areas of globe
- Minimum topographical, geological, hydrological, physiographical, limnological, meteorological, soil, vegetation, and wildlife disturbances
- Minimum use of land, water, water space, air, and air space
- Minimum input of solid, liquid, gaseous, and heat waste into ecological context

ORGANIZATIONAL CRITERIA

- Maximum centralization of coordination functions, maximum decentralization of decision-making functions
- Maximum compatibility between different energy systems, as autonomous energy units designed for use by single families, schools, health units, etc.

USER CRITERIA

- Maximum value placed on 100% of humanity as energy user; sufficiency – enough energy for everyone; accessibility – enough distribution to everyone
- Maximum quality control of energy artifact, system, or service

- Maximum reliability of energy artifact, system, or service; maximum use of back-up systems
- Maximum durability of energy artifact, system, or service
- Maximum ease, simplicity, and clarity of use of energy artifact, system, or service
- Maximum stability and consistency of output of energy artifact, system, or service
- Maximum cultural, esthetic, and individual human option diversity
- Maximum decentralization of information flow
- Maximum use of feedback
- Maximum indexing and cataloguing of energy systems, parts, services, and outputs
- Maximum knowledge about energy system interactions with all other systems, especially the ecological context

QUESTIONS/EXERCISES

1. What is an evaluation?
2. What are criteria?
3. What kinds of criteria will you include in order to choose from your inventory of alternatives?
4. What criteria would you use if you were going to design your own house?
5. What criteria do you use in selecting the food you eat?

7. DESIGN THE PREFERRED SYSTEM

What would your preferred system look like?

What elements would it contain?

How would it work?

Efficiently running systems often have parts that if tested separately would perform inefficiently. This understanding is implicit in the definition of synergy: the behavior of a system unpredicted by the sum of its parts. A chain is as strong as the total interaction of its links.

Designing the preferred system is the step where you construct a detailed plan or blueprint of your ideal system. The plan is an organization or description of related elements that, if implemented, could resolve a given set of problems.

You can design the preferred system by:

1. Considering the values and goals expressed in the preferred state
2. Selecting the appropriate alternatives
3. Integrating the alternatives you have selected into a coordinated system

Selecting the appropriate alternative elements and integrating them into a preferred system involves several steps. First, you determine which of the alternatives in your inventory meet the requirements or specifications of your evaluation criteria. Next, inventory the relevant environmental conditions of the geographic area (global, regional, local) for which you are planning. For example, if you are designing an energy system, you might list solar radiation, density, precipitation, ecosystem types, natural available resources, average daily wind velocity, etc. Then determine which of the qualifying alternatives are appropriate to your plan by matching the environmental conditions required by each to the existing conditions of the area. For example, a wind-powered generator would be appropriate in a mildly windy area while a solar collector would be inappropriate in an area that receives very little solar radiation. If it is apparent that there are few if any appropriate alternatives that would contribute to the resolution of the problem, you should outline a set of preferred performance characteristics for several ideal alternatives. These criteria can then be used by a design team for development of new alternatives and artifacts.

The final step is integrating the appropriate alternatives into a working system where all of the parts are functionally interconnected and coordinated. This step usually involves experimenting with different contributions of elements until a workable solution is achieved.

When you are organizing your preferred system, consider the following factors and describe the in detail:

1. How the system would operate and function
2. How the system would be managed and regulated
3. How the system would differ from the present system
4. How the system would be monitored so that evaluation of its performance could be made
5. How the system would increase the personal freedoms and number of learning opportunities for people
6. How the system could adapt to further technological innovations and social change
7. How the system could be assimilated to a wide range of cultural systems presently existing

The preferred system can be described with many of the same tools you used to describe the present state. For example, you might develop an input/output diagram showing all of the flows through the system. You might also diagram the arrangement of all of the different components and processes of the system. Trend charts could be developed to show how such a system would contribute to the conservation of depletable natural resources and/or increase the levels of adequate distribution of essential goods and services.

Following your original intentions, the plan should emphasize the level of aggregation (global, regional, community or single dwelling unit) that you chose to focus on, but it should also describe the interrelationships of similar functional systems at all levels of aggregation. For example, a community food system could be related to the regional and global food systems or vice versa.

A design science plan should not be confused with an outrageous vision of the future or speculative fantasy; but neither should it be confined to present modes of thinking, political constraints or projections of what is likely to happen.

Design science deals with what is technologically possible but not necessarily with what is politically probable. The primary constraints on the plan are technological (is it possible given current know-how?) and ecological (is it compatible with natural systems?). A plan uses what is currently available in resources, technology, and know-how. For example, nuclear fusion could not be included in an energy plan because fusion is presently not a technologically feasible energy source.

The unique quality of the plan is that it is based on **what you want** and **what is possible**. It shows how a system could be organized to fulfill your preferred values and goals. It is real to the extent that you can organize yourselves and the environment to realize the plan. In some ways, this planning stage can be likened to what an architect does in designing and specifying the elements of a new building or system of buildings. Resources, wants, potentials and constraints are all integrated into an image – a blueprint – of a preferred system.

QUESTIONS/EXERCISES

1. What is a plan?
2. What is a model?
3. What levels of aggregation are you going to include in your plan?
4. What technologies are you going to use in your plan?
5. What geographic, climatic, and ecological conditions are you designing for?
6. Design your diet for the next week:
    a. What foods will you eat?
    b. What is their nutritional content?
    c. Where will you get the food?
    d. What tools will you need to prepare the food?
7. Make a plan of a house you would like to live in and consider the following functions:
    a. Energy sources and use
    b. Water and waste systems
    c. Food preparation and storage
    d. Lighting
    e. Space configuration
    f. Materials
    g. Construction tools
    h. Structure of enclosure

8. DEVELOP STRATEGIES FOR IMPLEMENTATION

Once you have designed the plan of your preferred system, the next questions to be resolved are: **How do you get from here to there – from the present to the preferred state? What stages and levels of implementation do you have to consider?** A strategy is an arrangement of all the steps that must be completed along a time line showing the order in which they must be done. At the left end of the time line is the present problem and at the right is the proposed future. Along the time line will be the **"things which need to be done"** to get to the preferred state. When you take a trip by car, you have to pass through certain points to get to your destination. You must stop to eat, to get gasoline, and to rest.

In developing a complex strategy, it becomes obvious that all of the steps cannot be included on a single time line. In this situation you have to find ways of dividing the strategy into separate time lines. These lines can be either parallel or overlapping. There are two major ways of dividing the strategy. The first is to separate the implementation steps into different aggregate levels such as single dwelling unit, neighborhood, community, region and global. The next breakdown is to further subdivide each of these levels in terms of the different functional areas. For example, you might want to divide the implementation steps of a regional food system into the following subsystems: production, transportation, processing, storage, distribution, consumption, waste recycling, etc.

The following chart is an example of a sub-strategy of a global energy development plan proposed in **Energy Earth and Everyone**. The development of wind power is described at different aggregate levels along a ten year time line.

An essential question to be asked in developing a complex strategy after the total implementation period has been determined is – what stages of development must occur at what point during the overall implementation period? This kind of scheduling is **"determining first things first."** A hydrogen-powered transport vehicle, for example, has to be prototyped, tested, and proven feasible before a transportation using this vehicle can be designed and implemented.

A detailed strategy will also address these questions (not in order):

1. Who will implement the strategy?
2. How can they be invited to participate or be mobilized?
3. What tools and artifacts will be needed?
4. How and when can they be produced, distributed?
5. How can the strategy be evaluated?

How various groups of people could support and participate in the implementation of a system should be considered at this point. You might want to specify how increasing the general awareness and participation among those people who will be affected by the plan could be integrated into the entire process from beginning to end. For example, showing people that fossil fuel costs will eventually become prohibitive could help increase the awareness of the energy situation and encourage people to participate in an alternative energy development plan.

A helpful exercise in developing a long-range strategy is to describe the preferred system and to work backward to the present describing the necessary steps which lead to your goal. As you work backward to the present, you will find it is helpful to frame the different steps in the prevailing social context so that the plan appears both logical and implementable. For example, you could identify actual institutions, organizations, agencies and individuals either engaging in or capable of engaging in the prescribed steps of the strategy.

There is a proposal in the global energy strategy, **Energy Earth and Everyone,** to create a globally coordinated system of information clearinghouses to monitor, collect, and distribute data regarding ongoing research and development in energy systems. These clearinghouses could serve an educational function by keeping the public informed of potential alternatives, as well as providing substantive information to assist public decision-making processes.

Again, the intention of this strategy is not to show what will happen, but what can happen over time if scheduled steps of development are implemented.

A design science strategy is a logical sequence of events that shows how, starting from present conditions, a future preferred state can be achieved. A strategy is the "bridge" from the present "problem" state to the future "preferred" state.
The more comprehensive and anticipatory is a strategy, the better its chances of effecting the most positive change for humanity. In developing a comprehensive strategy, all the variables that affect the attainment of the global should be taken into account. In defining the problem, these variables are explored for their effect on the problem, and when the solution is defined, the comprehensive strategy describes the implementation of the solution.

QUESTIONS/EXERCISES

1. What is a strategy?
2. What stages of implementation will be necessary?
3. How long will each stage take?
4. What industries and commercial services are involved in this strategy?
5. Who are the users or consumers of the plan?
6. Who are the decision-makers that will be involved? When will they become involved?
7. Make a schedule of all the things you would need to do to make a 400 square foot vegetable garden in four days. (Imagine turning a backyard into a garden.)

6. DOCUMENT THE PROCESS

During every step in the design science planning process it is important to assemble a file and to record all research and group sessions. This documentation provides the raw material to produce a finished report after your work is complete. While the objective of your group may not be to publish and distribute a finished document, recording the progress of the work is often the only possible way to "store" the generated information for future referral. Design science teams often benefit from related work done by others. Seeing different approaches to similar problems can provide insights into one's own work as well as help to avoid duplication of effects. The work that you produce will likely be useful to other groups which follow. The more thoroughly the entire process is documented the more valuable the report will be to you and to other groups.

Design science teams can document their work using all or a combination of the following formats:

Research reports
Files of research articles
Bibliographies
Essays
Journalistic articles
Charts/graphs
Drawings
Audio and video tapes
Physical models
Photography
Blogging/Wikipedia
Computer presentations

After all of the material has been collected and the group process has been completed, a smaller documentation team can then compile, edit, and otherwise put into presentable form the results of the process.

QUESTIONS/EXERCISES

1. List different ways you can document your work. Decide which methods you will use.
2. How would you do a film simulating your group's process?
3. How would you design an exhibit of your plan?
4. Write a research report on an alternative you have investigated.
5. Write a summary of the problem state of healthcare delivery in the community you live in.
6. Write a report on the values and goals your group generated and how you came to agree on a shared set of goals.

7. TAKE THE INITATIVE

Initiative springs
Only from within
The individual
Initiative can neither
Be created nor delegated
It can only be vacated
Initiative can only
Be taken by the
Individual on his
Own self-conviction
Of the necessity
To overcome his
Conditioned reflexing
Which has accustomed
Him heretofore
Always to yield authority
To the wisdom
Of others. Initiative
Is only innate
And highly perishable.

- Buckminster Fuller

The design scientist undertakes fundamental invention, self-underwriting, development and experimental proof of inventions as demonstrated for instance by the Wright Brothers wherein the design science professional will be equipped with all the economic, legal and technological knowledge necessary for reducing such inventions to going industrial practice.

- Buckminster Fuller

Up to this point we have discussed the step by step method by which you can determine what needs to be done and how, but several important questions still need to be answered.

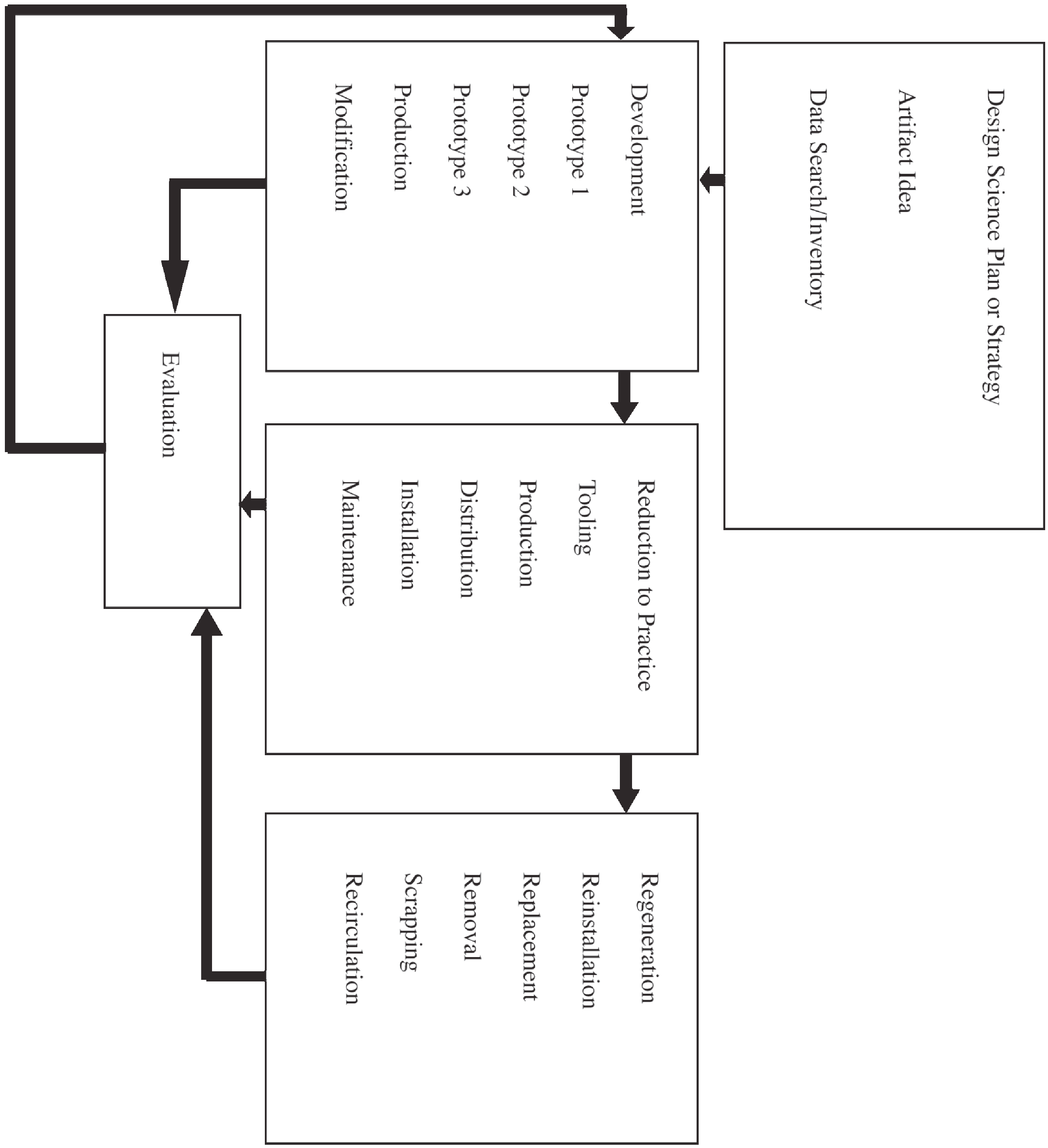
What do I do with the plan?
How can I hope to implement it?
How can I bring about a positive change in the world?

There are three ways for your or your group to further develop your work and to help bring about positive change. You can:

1. **Develop tools or artifacts** called for by the design science strategy you have formulated
2. **Communicate the plan** to those who would be involved, affected, or interested
3. **Initiate a larger planning process** which includes seeking the participation of those who would be involved in implementing the plan; or all three can be undertaken concurrently. We will consider each in turn, pointing out the relations of each to the others along the way.

DEVELOPING THE ARTIFACT

The design science process thus far has furnished you with a supporting rationale and a frame of reference which tells you what is needed. What is needed can often be translated into physical artifacts. This is the first and most important output of the design science process. Since the implementation of your plan will likely require developing artifacts which have not yet been invented or tested, you should compile a list of the artifacts that need to be "invented." Along with the artifact, state the preliminary specifications for its performance. These performance specifications or design criteria, are specific guidelines for what the artifact is supposed to do in terms of materials and energy usage, safety, performance, ecological impact, efficiency and adaptability.


Design Science Plan or Strategy
Artifact Idea
Data Search/Inventory
Development
Prototype 1
Prototype 2
Prototype 3
Production
Modification
Reduction to Practice
Tooling
Production
Distribution
Installation
Maintenance
Regeneration
Reinstallation
Replacement
Removal
Scrapping
Recirculation
Evaluation

Example: the global design science strategy formulated in the book **Energy Earth and Everyone** defines the need to harness the Earth's income energy sources. After studying the energy flows and concentrations through the whole Earth system, the winds of Antarctica were seen as a potential source of energy. Because of the unique conditions in Antarctica, a special artifact is needed to harness these winds. Most windmills build to date have been primarily designed to harness low intensity winds of the planet – winds blowing from 7 to 25 mph. Winds below or above these limits result in either no power or damage to the windmill. Winds in parts of Antarctica average over 28 mph for 340 days per year and often exceed 100 mph. To harness these winds, a wind turbine specifically designed for high speed winds is needed.

Now, an artifact – a high rpm wind turbine capable of functioning in the Antarctic has been identified, can be built, refined, and then utilized to meet the stated need. Design, building, and testing the artifact involves a specific design science process. The process, originally formulated by Buckminster Fuller, is a systematic outline for designing an artifact. In section 1, **Development**, the idea for the artifact is developed into a design and workable prototype. The first step is to get more information by making a comprehensive search of the related subjects. This search should tell you whether your idea or a similar one has already been reduced to practice (or attempted) when, where, how, what went wrong or right, etc. Examples of related areas in the Antarctic windmill example include:

Windmill design (is there already a high rpm windmill or one which could be adapted?), helicopter rotor design and construction, tower design and construction, specific weather and geographical conditions in Antarctica (where is the best spot for a forest of windmills in the Antarctic from the point of view of the wind, from the point of view of logistics), materials science (which materials are best suited to the Antarctic extremes); local and remote companies, agencies and authorities in the field whom you can contact either personally or via email, materials and energy costs and economies of scale.

The next step, after all the relevant information has been gathered, organized, and integrated, is to begin the actual design. A first prototype is built. If parts for the artifact are available, they are ordered and integrated into the desired unit. If apparatus is not available, then you must begin to fabricate the artifact from "scratch." What an individual is able to do him/herself is dependent on his/her own unique background, training, inclinations and the demands of the design. The design scientist is a synthesizer, an integrator of already existing parts into new synergetic arrangements. Obviously, an individual cannot mine, refine and alloy the various metals needed for a windmill, nor should he or she be expected to have all the skills necessary to reduce a complex idea to a physical artifact. The design scientist needs to be skilled in knowing how to get anything that needs to be done done; this entails knowing who can do what, and where, when, and how. One very beneficial side effect of this process is that the design scientist can obtain a comprehensive education by following his or her idea through to completion. Many skills and talents are brought into focus at one time or another in the process of reducing an idea to ongoing industrial practice.

Once the first prototype is built, it is then tested and refined into a second prototype. It is usually necessary to repeat this cycle of prototyping, testing, and refining an average of three times to work out all the bugs in a design. The third prototype should fulfill the performance specifications set out in the beginning of the Artifact Development stage, or those specified after more information has been gathered.

The prototyping of an idea, and the subsequent testing of that idea as a physical artifact to see whether it is indeed a viable alternative can be done by an individual or group. The next stage is the actual industrial manufacture of the working prototype, the production design, tooling, production, and subsequent distribution, installation, maintenance, and service. Because these steps usually require more resources than an individual or small group could bring to bear, the active support of a much larger group and its resources may be needed at this point. This is where the other two outputs of the design science process, "communicating the plan" and "initiating a larger planning process" enter the picture.

COMMUNICATING THE PLAN is the documentation and communication of the work done in the design science planning process. It includes the basic information and context of what the problem is, what the preferred state is, the alternatives, the strategy, etc. This documentation is put together as a report that can be sent out to the "authorities" in the field and other related individuals, groups, corporations, organizations, and government agencies that were identified in the course of the planning process for evaluative feedback. A new document which incorporates this feedback is written and distributed to the public. This documentation stage is a very important step in the design science process. Science is a collective effort in which current investigators are indebted to those who have come before. It is very important that any design science experiment or testing of a hypothesis (e.g. can humanity feed itself on a regenerative basis?) be recorded so that others who will carry the work further or in different directions can profit from the work.

INITIATING A LARGER PLANNING PROCESS is related to the preceding outputs of the design science process in two ways. As it has already been pointed out, reducing an idea to an industrially produced artifact may involve more resources and skills than the individual needs to communicate the idea for the artifact (and the supporting rationale of the whole design science strategy) to those who have the necessary industrial resources and capabilities. You have learned who these individuals, groups, and corporations are in the initial search phase of Artifact Development.

The second way in which initiating a larger planning process relates to the other outputs in furthering the implementation of the larger developmental strategy of which the artifact is only one part. In all planning it is crucial to involve the people who will benefit by a particular plan in its development. The purpose of a design science plan or strategy is primarily the testing of a hypothesis and the development of alternatives rather than planning for others. Once a new option or alternative has been developed it can then be widely disseminated and a larger planning process instituted.

In this later process, those who the strategy would effect can become involved in the process. To a degree, this will be similar to the effort that the individual design scientist or small group has already gone through. In no way is this a meaningless exercise; for the people who will be effected by the plan need to know, need to find out for themselves (and not be told by "experts"), just what are their collective goals and what are the limitations and possibilities of their specific situation. People should plan, not "be planned for" because one of the most beneficial aspects of planning is the educational process which takes place during the actual planning. Beyond this, for any complex development plan to succeed, it needs the full understanding and active participation of all the people involved in the plan.

As stated before, the ultimate goal of the design science process is to bring about constructive change; to allow everyone on Earth the option of being a "have" rather than a "have not." Sub-goals, or steps, along the way to this overall goal include the generation and testing of new options for humanity, the development of detailed strategies for the realization of new artifacts that are needed for a strategy, the initiation of a larger planning process, and the self-education of the design scientist.

If 1) the artifact which is perceived to be needed for the strategy's realization is prototyped and tested, then mass produced and distributed, maintained, replaced, and recycled when there is an improved item available; 2) the development strategy is documented, made widely available and feedback elicited; and 3) a decentralized local planning process is instituted in the specific areas where the design science development strategy has furnished new alternatives, than the design science process has achieved its goals. But it should be clearly understood from the beginning that goals are always being revised, clarified and restated and that **what design science seeks to do is redefine goals and create new options**. Although, the chances that these goals will be achieved rapidly may be slim, design science involves a long-range perspective which includes the knowledge that everything has its own gestation rates. For a human baby, it is 9 months, for an elephant it is 21 months, for an artifact or comprehensive design strategy it is usually considerably longer. As in any long distance voyage, period navigational fixes are taken and subsequent course corrections are made in order to "stay on course." The same applies to the long-range goals of design science. New information will alter the existing information; as goals are approached, new goals emerge.

QUESTIONS/EXERCISES

1. What is initiative?
2. What initiatives could your group take to further the development of your plan?
3. What initiative could you take?
4. How would you communicate your plan?
5. What artifacts could you or your group develop?
6. Make a list of authorities you would like to submit your plan to for feedback.
7. Who would you contact if you wanted to initiate a larger planning process?
8. What specialists would you need to assist you in developing the artifact you have chosen?
9. Draft a letter or email to a public decision-maker explaining your work and the significance of your plan to your community's future.

Origins of Design Science

R. Buckminster Fuller has been variously described as an inventor, mathematician, poet, cosmologist, architect, comprehensive designer, philosopher, and scientist. His comprehensive thinking in many fields has led to the development of a philosophy that has manifested itself in practical design. Many of Fuller's writings are collected essays that chart the complex path of his own evolution; however, throughout his books and publications, he invariably returns to a common theme and purpose: that due to technological advances, there are ample resources on Earth to provide for all of humanity at a higher standard of living than ever known before, and that humanity can and may well be comprehensively mutually successful.

Fuller charts the trend of humanity's evolution from a situation of only one percent of humanity being adequately maintained on Earth, to the current situation of 44 percent of the human population being adequately maintained, despite the fact that the finite stock of resources per person has decreased. For Fuller, the explanation for this phenomenon is found, not in the realm of social politics, but in the unparalleled advances brought about by the proliferation of scientific discovery, technology and industrialization.

Resolving that the trend could continue, and that the world could thus be made to work for 100 percent of humanity, Fuller asked himself the question "what could humanity in general, and one person in particular, do to achieve this goal?" The historical evolution of his attempt to answer this question is also the evolution of design science. This evolution, demonstrated in Fuller's own life, can be divided into three major parts: Dymaxion design, world resources inventory, and synergetic geometry. A summary of his work in these areas follows:

Dymaxion Design

A pivotal juncture seems to have occurred in Fuller's life in 1927 when he deliberately set out to be a comprehensivist (a person who is seeking to integrate and synthesize information out of a myriad of specialist disciplines). The precedents for this decision were formed throughout the previous decade of his life. He was one of the last groups of young naval officers to receive comprehensive training in navigation, ballistics and logistics before, ironically enough, technological advances made naval officers specialists. This training, when navies were masters of the world, greatly influenced Fuller's thinking. He became interested in finding ways that the technology of weaponry could be applied to livingry and the logistics of war applied to the logistics of peace. Fuller's ventures in the housing industry and the subsequent commercial difficulties of those ventures, coupled with the personal loss of his first child, tempered his decisions. He emerged from this difficult period as a self-disciplined comprehensivist, ignoring specialization and commercialization to formulate a more adequate model for his own life and the lives of his fellow humans.

These concerns resulted in the development of a series of designs and inventions, the first being the Dymaxion house (1927). The house was a radical departure from convention. It was hung from a mast in triangulated tension, and was intended to be a mass-produced, high-quality, low-cost shelter. Rather than designing a house for a client, as was and still is the traditional practice of architects, Fuller attacked a whole host of social, economic and political problems by scientifically designing a prototype for low-cost mass-producible housing. Several people expressed interest, and other actively encouraged the project, although the housing industry as a whole ignored Fuller's design. He later designed and built a prototype for a mass-produced, all-purpose transport machine, the Dymaxion car (1933), which combined mechanical efficiency with advanced design. Three vehicles were produced, but the automobile industry, like the housing industry in prior years, showed little interest and foresight. Other artifacts Fuller designed and produced included the Dymaxion bathroom (1937) offering an efficient, lightweight, safe and non-polluting personal hygiene module which the plumbing industry ignored. These were not setbacks for Fuller because rather than promoting the commercial success of these projects, he was intent on testing his design theories and demonstrating that humanity had new options. Many of the basic ideas in Fuller's original designs are only now, more than 50 years later, being used in industrial design.

In 1940, Fuller unveiled another house, this one designed to provide temporary shelter. It utilized a cylindrical design of corrugated steel similar to the highly practical agricultural grain bins that had inspired the design. In 1945, Fuller continued his attempts to advance his concepts of housing with the design of the Dymaxion Dwelling Machine, the first prototype of the "mass-produced installable anywhere around the world, scientifically advantaged dwelling unit." The prototype was manufactured in an airplane factory, and it emulated all the latest design advances of airplane manufacturing technology.

The culmination of this design period combined Fuller's explorations into synergetic geometry with his philosophy of providing shelter by doing more with less. Their integration resulted in the design of the geodesic dome (patented in 1954), perhaps his most widely accepted contribution to the goal of sheltering humanity. The geodesic dome is the artifact that probably best reflects the fruition of Fuller's ideas concerning the beauty of nature's principles, when used in technological design.

Realizing the limited potentials of political systems, and proposing instead a focus on the potentials of design, Fuller was also demonstrating how a person could take the design initiative and create solutions to the problems that confronted humanity. The Dymaxion designs provided the first concrete recognition by Fuller of how humanity might attain the goal of providing for all of its life-support needs by applying the principles of science to the problems of design. The designs have continued to emphasize Buckminster Fuller's views about philosophy: "you can't better the world by simply talking to it. Philosophy to be effective has to be mechanically applied."

World Resources Inventory

Undaunted by the commercial resistance to his early design and aware that they were ahead of their time, Fuller developed a system of thinking which led him to an increasingly more comprehensive perspective. While experimenting with developing the technologies that he felt would help provide basic life-support for all humans, he was also formulating a comprehensive design philosophy. He began collecting a vast data bank that he called "Inventory of World Resources, Trends and Human Needs." Though he began many years earlier, he made the first systematic update of that inventory in 1927. The world resources inventory set the stage for Fuller's explorations into forecasting and comprehensive planning. He tried to ascertain and interpret the significant trends of human evolution.

In 1936, Phelps-Dodge asked him to make a comprehensive study of the world's resources and trendings, in particular relating the role of copper to the rest of the world's resources. In 1938, Fuller served as consultant to *Fortune* magazine, producing a special 1940 anniversary issue which compared world resource reserves to United States resources. In the war years, 1942-44, Fuller was chief mechanical engineer for the Board of Economic Warfare and was involved in the Inter-agency Alternate World Resources Substitution Committee where he helped formulate a long-range economic plan for Brazil.

The accumulation of data verified some of his earlier hypotheses which contradicted commonly held assumptions of Malthus and Darwin that the planet was unable to support more than a fraction of its human population with available resources. With his comprehensive perspective and understanding of previously unknown technologies, Fuller envisioned a responsibly designed utilization of the planet's resources to sustain all human life.

In the process of developing one of his best known metaphors, "Spaceship Earth," Fuller observed that the only equipment Earth did not provide for humans was an operating manual. He set out to discover clues to that manual by investigating the generalized principles discovered by science to be operating in nature, and to apply them to the fundamental design problems confronting humanity.

The problem of distribution of wealth and resources, typically an economic problem, is the subject of another of Fuller's metaphors, the World Game. In Fuller's words:

"The World Game is a scientific means for exploring the expeditious ways of employing the World's resources so efficiently and omniconsiderably as to be able to provide a higher standard of living for all of humanity. The World Game employs design science to produce progressively higher performance per unit of invested time, energy and know-how per each and every component function of the World's resources."

Fuller envisioned the World Game as an ongoing activity for utilizing the information generated by the world resources inventory in which people could plan and design strategies for making the world work.

Synergetic Geometry

Fuller's third major avenue of exploration has been in the area of mathematics and geometry. In his exploring of ways of doing more with less, Fuller found that what humans called technology was really an adaptation of the ultimate technology of nature. The better we can understand how nature works, the better we will be able to design our own tools and live in harmony with our environment. Fuller's geometry was an articulation of his belief in an ultimate a priori existence of fundamental order in universe, operating through the generalized principles and capable of being described by numbers and coordinate systems. "Local design configurations, whether they be crystals, molecular biology or human structures, seem to be adaptations of generalized patterns. It is nature." Fuller reminds us, "that always uses a minimum amount of materials and energy to produce maximum results manifested in her exquisite technological forms."

Fuller saw that conventional mathematics resulted from humanity's historical experiences with local phemomena, which traditionally seemed to be rectilinear and on a flat plane. A 90° coordinate system evolved from these experiences along with the XYZ axes of Cartesian space. The infinite two dimensional planes of Euclidian geometry are another example of an imaginary system that no longer corresponded to the reality that physics had discovered. Science had long since gone beyond those conceptions of space, and Fuller reasoned that the old mathematics was hardly capable of accurately describing relationships to a space that physics had redefined. Fuller's geometry was a departure from convention because it discarded the rectilinear cubical basis for structures in favor of the development of geometrical forms based upon the tetrahedron. Synergetic geometry is based on a 60° coordinate system as opposed to the 90° convention. Fuller said that the universe in reality orients its events in 60° relationships, doing it with systems of triangles, tetrahedral and spheres.

Another of Fuller's concerns, "the geometry of thinking" (the subtitle of his book *Synergetics*), was that language is unfortunately often inaccurate. He said that words carry with them a multitude of values and attitudes that convey mis-information about physical reality. The words "sunrise" and "sunset" are examples of how our word perceptions have been trailing five hundred years behind our scientific knowledge. "Any scientist knows the sun is not setting, the earth is revolving to obscure the sun." Fuller emphasized that generalized principles can be geometrically modeled to permit rational translation into forms of communication that can be understood by designers, scientists and laypeople alike.

Synergetic geometry further emphasizes Fuller's search for a grand strategy for all problem solving, and within the geometry the reoccurring theme emerged again; "there is an inherently minimum set of essential concepts and current information, cognizance of which could lead to our operating our planet Earth to the lasting satisfaction and health of all humanity."

The geometry, the design and philosophy are intricately interwoven into comprehensive design science, forming the operating strategy and assumptions for Fuller's life as well as the elements of a blueprint for the intelligent use of technology to make the world a better place to live.