

# ADAPTIVE BUILDINGS THROUGH EVOLUTIONARY DESIGN

Towards more sustainable buildings: project design process as a complex  
adaptive system

by

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## ABSTRACT

Just as natural adaptation comes from evolutionary processes that lead to 'fit' of an organism to its environment, adaptive buildings come from design processes that lead to the 'fit' of a building to its environment. A building which 'fits' its environment is considered to be sustainable. The environment is defined to encompass economic, social and ecological context. Buildings are artifacts chosen by a designer from among possible designs based on human value judgements about internal and external constraints. It is hypothesized that a project design process will result in more adaptive buildings when: first, the project team has sufficient relevant information related to the environment; second, the project team is sufficiently motivated to 'fit' the project to its environment; and third, the project team develops specific targets for resource consumption. Design process occurs at both the team level (project design process) and the individual level (design process). A model of design as a complex adaptive system is developed. The model shows creativity as a phenomenon arising from the interplay of two forces: pattern and constraint. In design, a designer transforms the 'chaos' of new and unintegrated input (change agents) into emergent pattern by integrating the input so as to be consistent with existing patterns and responsive to constraints (conservation agents). This integration results in the 'click' which designers experience during design activity. The 'click' signals boundary-breaking between the designer's internal and external (content and context) constraints and patterns. Dynamic equilibrium arises from balancing between change and conservation of input and between integration and differentiation of that input. Total equilibrium arises from combined conservation and differentiation. Further it is suggested that oscillation between integration and differentiation will result in creative breakthroughs. The model is researched in a case study of a built project, tested in a design exercise in a seminar setting with students and professionals, and discussed in an interview with a noted designer. Indicators for sustainable buildings are developed. The model provides a new description of design process and the findings indicate that its use is likely to result in more adaptive buildings as measured by indicators for sustainability.

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## DEDICATION

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## CHAPTER 1

# ARCHITECTS: AN ENDANGERED SPECIES?

### *Statement of the Problem*

## 1.1 Introduction

Man has lost the capacity to foresee and to forestall. He will end by destroying the earth.

Albert Schweitzer

The dissertation describes and critiques the contemporary building project design process and its resultant product in Western culture. It proposes that changes to both the design process of the individual participants and the interactions of the project team are necessary for a more *adaptive* product. An adaptive product is one that can respond to economic, social and ecological constraints and can adapt to changing constraints over time. Just as natural adaptation leads to 'fitness' of an organism to its environment, so adapted buildings will 'fit' their economic, social and ecological environment. Buildings which 'fit' their environment are more likely to be sustainable.

Evolution is a process without 'design' and its products 'fit' their environment through the incremental processes of replication, variation, selection and retention. When humans design, they compress the amount of time required for natural evolution by artificially accelerating these processes. A designer anticipates the performance of a design product in its environment in relation to the constraints that the designer proposes will be operational on the product. The real constraints apply after the design is built and it is only after a long period that we can tell if a building has 'stood the test of time'. The constraints that are operating during design are contrived by the designer in lieu of real constraints. They are artificial. If the designer uses inappropriate or irrelevant artificial constraints then the design will not be adaptive to its real

environment. It is the human ability to project possibilities and examine them abstractly that places humans at the 'top' of the evolutionary tree. However, in design this ability enables humans to shortcut the natural evolutionary adaptation that comes from concrete, incremental responses to the real environment.

Evolutionary adaptation is the hallmark of indigenous architecture. The form of indigenous buildings evolves slowly and is adjusted incrementally to better 'fit' its environment. There is no single designer for an indigenous building. The process is social and accretive and amounts to a series of tests for the fitness of the product: a process of natural selection. Since the emergence of design as a separate activity from building, individual architects have been the generators of building design concepts. The ability to imagine form in abstraction without the necessity of adaptation to the real constraints of the world means that designers respond to an artificial set of constraints. It is the designer who decides which constraints are important.

The advent of modernism has produced a generation of buildings that are maladapted. By maladapted I mean wasteful of resources, awkward in their context and harmful to community health and well-being. In the natural world maladaptation leads to extinction. Designing buildings which are wasteful of energy and have short lifespans has short term economic benefits for developers and architects but it is destructive for society and the environment in the longer term because of inefficient use of resources and lack of respect for the deep needs of humans and their communities to have healthy, timeless places for living, working and playing.

Sharon Butala, a writer who explores the roots of her creativity in The Perfection of the Morning (1994), describes her reaction to returning to teach in Calgary high schools after an extended stay on a ranch:

"I hadn't been inside such big buildings for any length of time in years, and I was surprised to discover how physically uncomfortable I was in them. Inside them I felt a disruption of my normal way of experiencing the external environment; I felt disconnected from my physical self. It was as if my body

didn't end after all with the surface of my skin, and that some invisible, exterior part was being subtly disrupted by the machinery running the building. I felt as if I were minutely and imperceptibly vibrating with the machinery - I've felt this in airports too - as if I couldn't locate my *self* inside my body because the buildings...were disrupting my normal way of functioning in the atmosphere. Leaving these buildings at the end of the day was a tremendous physical relief to me and I couldn't help but think about all the young people who were growing up mainly inside them, not even knowing that the buildings were warping, perhaps destroying a dimension of their humanity."

Natural resource sustainability is a critical issue for contemporary society and adapted buildings will contribute to sustainable approaches to resource management by conserving materials and energy. Adapted buildings will also support human development by contributing to social cohesion through the provision of healthy, safe, comfortable buildings that form an integral part of the physical manifestation of a community.

The discussion that follows focuses on building design but the principles could apply more generally to any type of project. Project is defined as "a temporary endeavour undertaken to create a unique product or service" (Duncan 1996). Environment is defined as economic, social and ecological context. The term *project design process* will be used to describe the entire delivery process for a building. *Design process* will apply to the process of an individual.

The goal of the dissertation is to outline a framework for a design process that more closely follows natural evolutionary processes and to suggest ways in which the project design process can change in order to result in more adaptive buildings. The framework focuses on the activity of design and suggests ways to make it more creative, efficient and effective using natural evolutionary processes as models. I argue that the use of a more 'evolutionary' design process will result in projects that are better adapted to their environments. I extend evolutionary process to the more general processes of complex adaptive systems (CAS) and draw on their process dynamics to construct a *design process framework*.

In order to bring the artificial constraints of the designer closer to the real constraints of the environment, in which the product will exist, designers must be aware of and attentive to those contextual constraints.

Humans have the capacity both to 'sense' their context and to organize their sensations into patterns. I argue that the root of an 'evolutionary' design process is an extension of both the human capacity for concrete sensation (which I call *integration*) and the human capacity for abstract pattern formation (which I call *differentiation*). I identify the components of these capacities and the dynamics of their interaction and suggest that their use will lead to more adaptive products. Further I suggest that their use will lead to more creative design. Creative design is essential for an *evolving* adapted product. I equate creativity with the process of boundary-breaking. The existing perceived boundaries of a situation are the constraints. Not only must the designer perceive the appropriate constraints for the design problem but they must also be able to transcend the constraints in order to reach an integration between the project and its context. As economic, social and ecological contexts change, good design must be able to respond appropriately. This co-evolution in the product is achieved through creativity in the design. Creativity is defined as valuable innovation. Since the rate of change in society is slow and in nature is very slow, one would expect the rate of change in design to be slow, but modernism with its reduction of time-space distances (Giddens 1990, 53) has speeded up the rate of change in design. Novelty has become an end in itself and the result is a series of unintended consequences as the product meets the real constraints of its context. The emphasis for most designers is on *differentiation*. The *integrative* tendencies are glossed over. The natural and social contexts (which are the object of the integration) become subsumed by the abstract search for differentiated products.

In this chapter, I discuss the reasons for the increasing marginalization of architects and the shortcomings of contemporary architecture, outline the traditional project design process, critique it and discuss criteria for success in the product. I introduce the theoretical basis of the dissertation, describe the origins of the proposed model of the project design process (which I call the framework) and outline the research questions which the dissertation addresses.

In Chapter 2, I review the literature of design theory related to evolutionary theory and complex adaptive systems theory, relate these to theories of creativity, discuss aspects of the brain and mind which suggest support for the framework and explain the framework. I develop the research questions related to the goals of the dissertation and discuss the rationale behind the framework.

In Chapter 3, I describe the case studies undertaken to explore the research questions.

The results of the case studies are given in Chapter 4 and a summary, conclusions and recommendations for further research are given in Chapter 5.

## 1.2 The Problem

### 1.2.1 Critique of the Product

The great temptation of any game is for it to become too self-contained, an activity of purely aesthetic pleasure or technical achievement...The artist concerned only with form, the engineer concerned only with technical solutions - the pursuit of art for art's sake, engineering for the sake of the engineer - can be challenged by more inclusive issues and social orders.

Carl Mitcham

Architects are becoming increasingly marginal in western cultures. The documented failures of modern architecture such as the Pruitt-Igoe housing scheme in Chicago (Jencks 1978) and the Bronx Development Centre (Mitchell 1993) demonstrate that the modern (and post modern and deconstructivist) paradigm of *'formal'* hegemony has failed. Social scientists have concluded that planning and design professionals operate from an 'expert' mode that effectively negates the possibility of citizens having meaningful participation in decisions affecting their community (Porteous 1977, Bender 1994). At the same time, increasing reliance on technological solutions to architectural problems has led to unintended consequences such as "sick building syndrome", accumulations of PCB's and CFC's, and global warming. In addition, our profligate consumption of resources and energy has contributed significantly to the present degradation of the natural environment (Lenssen and Roodman, 1995). However, even in the face of these demonstrated failings, mainstream architects and engineers still adhere to the paradigm of formal dominance and the tyranny of technopoly (Postman 1993). Much contemporary published work acclaimed by the profession is formalistic, non-contextual, experientially impoverished and socially alienating (Alexander 1979, Benedikt 1987, Harvey 1989, Hescong 1990, Kroll 1987, Postman 1993, Rybczynski 1986, Thomas 1997).

Despite the urgent, complex and interdependent economic, social and ecological issues in the world today, the profession of architecture marginalizes itself by emphasizing abstract formal issues and unquestioningly accepting technological innovation. It produces a net increase in society's problems as opposed to a net

reduction of those same problems (FIGURE 1). As well as being constrained within the present paradigm as a result of economic and social forces, architects are choosing to deal with a narrow and largely irrelevant set of constraints, related mainly to abstract ideology and fashion (Thomas 1997). As a result they are contributing unnecessarily to economic, social and ecological problems.

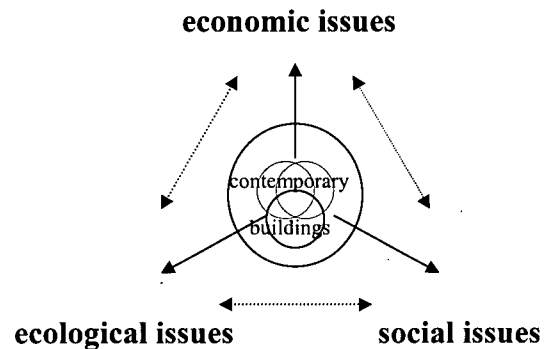


FIGURE 1 THE PROBLEM

#### 1.2.1.1 Economic Problems

Economic problems include: huge increases in public debt (in part to support our physical infrastructures) resulting in high taxation and further borrowing; the emergence of the global free-trade economy and the eradication of regional diversity; unique cultures becoming integrated into commodity production; the inability of our present economic system to deal with the costs of externalities resulting from our consumptive culture. The practice of architecture contributes to these problems by: emphasizing capital costs over operating costs; accepting fashion as a design imperative; and ignoring the external costs to society brought about by the resource and energy extraction and waste production inherent in the process of building (Lenssen and Roodman 1995).

### **1.2.1.2 Social Problems**

Social problems include: an expanding reliance on financially constrained governments to provide for the socially disadvantaged; a widespread perception of increasing violence in our society leading to a positive feedback loop of withdrawal from public life in our streets and public places; rising levels of regulation to deal with the problems arising from the growing complexity of our technological systems (another positive feedback loop); a widening gap between the haves and have-nots in the world which will inevitably lead to conflict. The practice of architecture contributes to these problems by failing to respond to the fact that building form: affects public life; contributes to personal security; and contributes to the health and well-being of the building occupants (Brolin 1976, Cole, Rousseau, and Theaker 1993, Goodman 1971, Wright 1995).

### **1.2.1.3 Ecological Problems**

Ecological problems include: global warming; ozone depletion; resource depletion; biodiversity depletion; and waste accumulation (Brown 1995). The practice of architecture contributes to these problems through design which promotes: profligate use of resources; ongoing high use of operating energy drawn mainly from non-renewable sources; excessive use of water; unnecessary construction waste and generation of emissions of toxic or destructive gases (Lenssen and Roodman 1995, Leclair and Rousseau 1992).

### **1.2.1.4 Summary**

The contemporary building design process has developed under a set of outmoded and potentially destructive assumptions and practices. The players involved in the act of creating a building (developers, planners, architects, engineers, landscape architects, interior designers, specification writers, code officials, contractors, sub-contractors, material suppliers) are complicit in continuing to practice while largely neglecting the long-term economic, social and environmental consequences of their actions. As the negative and previously unforeseen consequences of a short-term approach become more apparent, the public brings

into question the value of the experts who have promoted it. The professions involved are increasingly criticized and ultimately may well become irrelevant.

### **1.2.2 The Project Design Process**

“Design is, in essence, the giving of form to values.”

Reuben M. Rainey

Central to the actions of almost every player in the project design process is the individual design process.

“Design offers a variety of ways to reunite theory and practice for productive purposes” (Buchanan and Margolin 1995, xvii). It is the central activity in an “ecology of the artificial...Each artifact, each image, each idea contains something of the rationality, values and sensibility of the designer, but each is part of a broader and more complex dynamic system” (Manzini 1995, 230). The project design process is a complex, dynamic system of interactions of individual design decisions with differing levels of criticality. Out of this process a building is delivered which owners, operators, users and society live with for a substantial period of time.

It is imperative that we develop a building design process which: addresses the conflicts inherent in the present process; draws on the skills and creative energy of all the participants; and ultimately produces a building which is profitable for the owner and the local economy, is comfortable and healthy for its users and the community, stands the test of time by adapting to changing circumstances, operates efficiently and humanely, and minimizes damage to the ecosystems of the earth.

### 1.2.2.1 The Design Process

*[T]here is only one Design Space, and everything actual in it is united with everything else.*

And I hardly need add that it was Darwin who taught us this...We are not just designed, we are designers, and all our talents as designers, and our products, must emerge non-miraculously from the blind, mechanical processes of Darwinian mechanisms *of one sort or another.* [original emphasis]

Daniel Dennett

The design process has generally been considered to be unknowable (a black box) and a surge of research on design methodology in the sixties turned out to be of little practical value when designers realized that 'methods' were not easily applicable to the design process (Mitchell 1993). Subsequently, the focus shifted to the nature of the process and in 1979 Herbert Simon wrote:

"The artificial world is centered precisely on this interface between the inner and outer environments; it is concerned with attaining goals by adapting the former to the latter. The proper study of those who are concerned with the artificial is the way in which that adaptation of means to environments is brought about - and central to that is the process of design itself."

The separation of the process of design from the act of building can be traced back almost two hundred years to the establishment of the Ecole des Beaux-Arts in Paris in 1806 where the design problem was structured for the students into two parts: the *esquisse* and the *projet rendu*. The *esquisse* was a sketch by the student produced under invigilated conditions in twelve hours. During the *projet rendu*, which lasted about six weeks, the student developed the *esquisse* into a finished design in the design atelier (or studio). A jury then criticized the finished design. This general method is still very much the model followed today in architectural education. "Although design is the mainstay of a student architect's course, its theoretical bases hardly ever receive more than a fragment of the attention which the more obvious technical skills are given. Ability in design tends to be regarded as something that is largely innate; proficiency is picked up on

the way: by experience, by emulation and by luck.” (Manning 1968) Further, Donald Schon has said  
“[C]ertain features of designing are vague and/or inexpressible...And the utterances and silences of designers  
with respect to these features...are themselves ambiguous.” (Schon 1977, 70)

The one feature of the architectural design process that has received consistent recognition is that it combines  
the skills and abilities of both art and engineering. This can be seen in the range of university faculties where  
architecture schools are situated: from Liberal Arts to Applied Science. The apparent paradox that lies at the  
heart of the artistic and the scientific also lies at the heart of the design process. Like art, design is based on  
conjecture and like science, design is based on investigation. The defining characteristics of the two must be  
brought together to give an inclusive framework for design.

### **1.2.3 Summary**

What follows is a recognition that the way in which we make things, and the way in which  
those things act, has a profound effect upon how we ourselves are made, and what we  
become. In this frame, work on or with the ecological systems will always be equally a  
reaching out, a touching, and changing the social ecology, the ecology of community that  
demands the myth of the value of life as given from the elsewhere - the sacred.

Tony Fry

From the above brief analysis it can be seen that contemporary architecture has largely ignored the  
economic, social and environmental issues of our time and that our understanding of the design processes  
that have contributed to this situation is primitive. The laissez faire approach to design has led to a project  
design process that results in products which respond in a minimal way to the pressing social and ecological  
issues of our society. Some authors have speculated that there may be ‘ecological’ design processes that

would result in more adaptive products (Wann 1990, Orr 1992, Todd and Todd 1984). I explore the nature and dynamics of 'ecological' or evolutionary design processes and their impact on the product.

### ***1.2.4 Inferences and Hypothesis***

It is into this complex and delicately balanced system that we have self-organized our change machine whose design crudity is currently transforming the living system in ways which we find both uncertain and damaging to ourselves and the life around us.

C. A. Hooker

If one accepts that our society is producing maladapted buildings, then the architectural profession and the allied professions will have to change the process that is leading to this product. Owners, planners and other stakeholders must also have a role in transforming the existing process. If the products of the project design process are to be better adapted then, logically, the process must become more evolutionary. The project team must consciously invoke the processes of evolution (replication, variation, selection and retention). The artificial constraints adopted by the project team for the purposes of design must be brought closer to the real constraints of the natural world. Ways of encouraging these processes must be developed and they must be developed in three key ways. Firstly, the economic, social and ecological consequences of design decisions should be more explicit. There must be more information available to design teams to enable them to adjust their design decisions based on feedback about their effects. Feedback is a key to evolution. It enables selection and retention to occur. Secondly, the design team must be motivated to attend to these critical constraints. Motivation provides the energy needed to overcome the difficulties of variation. Business the same old way requires little effort. Innovation requires extra effort. Sustained effort comes from motivation. Thirdly, there must be a concrete commitment by the design team to focus on specific and common objectives related to the economic, social and ecological consequences of their decisions. Collective effort is necessary with the varying perspectives of experts and stakeholders to bring the

complexity of real constraints to bear on the artificial constraints used in the design process. It is especially critical that these varying perspectives are allowed to bear down on the early design decisions. Just as in evolution, speciation is generative and extinction is reductive. Early design moves which are discarded for any reason (valid or not) are not likely to be revisited (they have been selected out). Clever ideas that are adopted without being aired to the selective views of the entire team will survive (even though they may not 'fit' real constraints). The consulting team will be left to deal with the downstream issues generated by these early, inappropriate moves by applying patch-up measures. For example, elaborate, technologically complex and resource wasteful air movement systems become necessary when natural ventilation is not accommodated in the design from the beginning. Often the owner is left with a building that is problematic for the users and about which the community feels negatively. Their concerns and requirements must be considered early so that formative design moves take them into consideration.

## **1.3 Analysis of the Problem**

### **1.3.1 Ethics**

[O]ne questions whether the future will perpetuate the occidental end-games of limitless wastage and pollution or whether new dimensions of ethical practice will arise out of a new-found respect for the symbiotic limits of both being and cosmos....within which a critical practice of architecture will have to find its material. Kenneth Frampton

From the above accounting of the state of architecture it can be seen that the project constraints on which the profession are presently focused are, in the main, self-serving. The constraints of a project define its ultimate form. "Constraints map out a territory of structural possibilities which can then be explored, and perhaps transformed to give another one" (Boden 1990, 82). It is my contention that architects are largely ignoring the constraints of the ecological sphere and have limited concern for those of the social sphere. The strongest constraints for most contemporary architects are the constraints of the profession. The pressure to

make a living and gain prestige through doing work that is publishable because of its uniqueness is the overriding constraint for most architects. In order to survive within the present paradigm the architect must: cut fees (necessitating less care with a design); compete with other professionals and paraprofessionals for work (demanding an approach to design on a technical or engineering level); exclusively serve clients' needs (to the detriment of the public good); compete with 'star' architects (to establish credibility). All these conditions conspire to remove the architect from the ideal of the professional as an individual who serves the public good before their own good. I therefore argue that a return to an ethic-based profession is imperative. While still meeting the internal constraints of their own needs for financial and professional success, design professionals must place environmental concerns at the forefront when they design. They must refocus their attention on external constraints i.e. the environment. Altruism, in the sense of the willingness to forgo some good for oneself in order to help others, was speculated by Darwin to be the result of natural selection. Individuals who possess and use this characteristic will receive help in return from others and this tendency will be reinforced by social praise and blame. Kin-altruism or reciprocal altruism is readily explained by natural selection since helping kin to survive will ensure that one's genes are passed on. Broader altruism is attained through the human capacity to reason when it is realized that greater benefit might be gained for all with minor individual sacrifice (Rachels 1990). The issue of altruism is central to Garret Hardin's seminal article The Tragedy of the Commons (Hardin 1968). He concludes that care for the 'commons' is unlikely when it involves individual sacrifice.

The design process framework I propose is modeled after the natural processes that break the boundaries between internal and external conditions in natural systems. There are two forces at work in natural systems: pattern and constraint. I argue that if designers can break the boundaries between the internal and external conditions of pattern and constraint then content will move closer to its context and will thus lead to more adapted designs. Through *The Agents*: variation from within the system (change: C) and *adaptation* to the environment outside the system (conservation: D), The Boundary-breaking Vehicles: differentiation

(selection:  $\beta$ ) and *integration* (emergence:  $\alpha$ ) are brought into play. A matrix of these operations is shown in FIGURE 2.

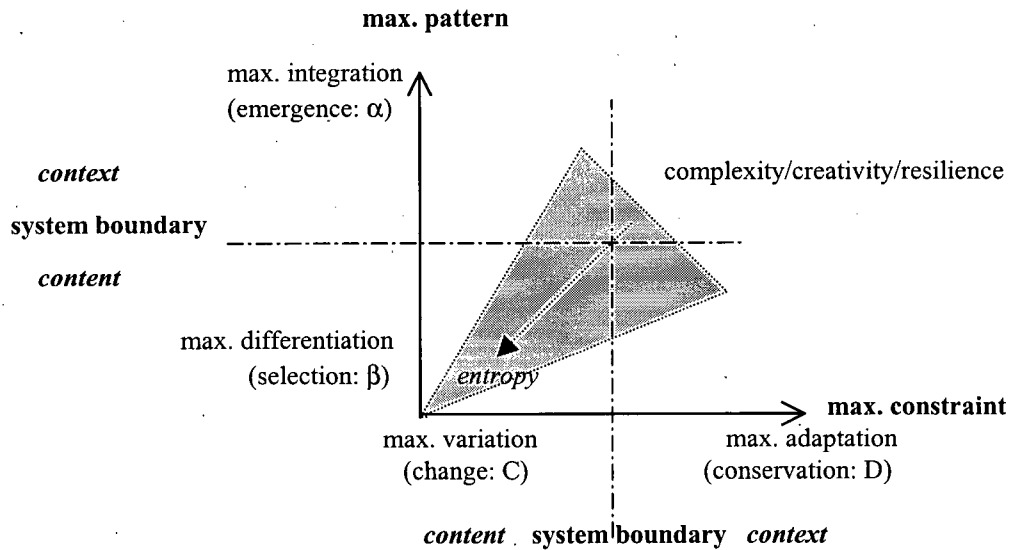


FIGURE 2 THE BASIC OPERATIONS OF DESIGN PROCESSES (after Dr. Lavkulich)

The catalysts that activate the basic operations in a system are called the *control parameters*. I propose that there are three control parameters for design (*information*, *inspiration* and *intention*) and these are based on the psychological processes of cognition, affect and volition. With education on the issues, new *information* is received, variation occurs and cognition leads to differentiation, selection, integration and emergence of *knowledge*. *Inspiration* leads to differentiation, selection, integration and emergence of *motivation*. Finally, with the *intention* of specific goals in mind, volition activates differentiation, selection, integration and emergence of *operation*. Through the control parameters, designers will be enabled to break the boundaries between their internal constraints (knowledge, motivation and operation) and the external constraints of the

environment. Similarly, they will be enabled to break the boundaries between internal system patterns and external system patterns. At the moment of transition from internal to external constraint or pattern a shift or “click” is experienced.

### **1.3.2 System Hierarchies and Levels**

The ‘solution’ to situations that involve a dilemma or paradox is to move to the next level in the hierarchy of the system. In the commons dilemma, the level at which the paradox is in effect is the level of the individual. If all the individuals operate on the basis of making their decisions within the framework of the next level in the hierarchy, which is the group level, then they will all gain equally. If they continue to make decisions at the individual level then they will all ultimately lose equally, even though for a time specific individuals stand to gain. “In the course of evolution, there appears to have been ample opportunity for cooperation to have assisted everything from humans to molecules. In a sense, cooperation could be older than life itself.” (Nowak, May, and Sigmund 1995, 81)

Using game theory and computer simulations Robert Axelrod has demonstrated how cooperation among unrelated individuals can evolve and remain stable (Cziko 1995). In society such cooperation depends on cumulative variation, selection, and propagation of shared beliefs and practices rather than genes. This inhibits selfish behaviours that could undermine the cooperative structure of the community.

The Prisoner’s Dilemma is a metaphor for the commons dilemma. It was developed from game theory in the early 1950’s. Each of two prisoners is asked whether the other committed a crime; their level of punishment depends on whether one, both or neither indicates the other’s guilt. If both cooperate (by not indicating the other’s guilt) they are rewarded with three points each. If both defect (by implicating the other) they get only one point each. If one defects and the other cooperates, the defector receives five points and the cooperator receives no points. Using the logic of maximizing one’s own gain implies that the best move is always to defect, irrespective of the opposing player’s move. This logic leads inevitably to mutual defection, which is

the worst outcome for both prisoners. Experience tells us that in real life other considerations come into play, such as altruism, societal pressure and the development of long term relationships. These considerations lead to strategies of cooperation in many situations (Nowak, May, and Sigmund 1995).

In computer simulations of the Prisoner's Dilemma it has been found that there is a definite trend toward cooperation but also that there can be abrupt transitions between lengthy runs of almost all cooperating and almost all defecting. Nowak, May and Sigmund compare this behaviour to punctuated equilibria in biological evolution. "Throughout the evolutionary history of life, cooperation among smaller units led to the emergence of more complex structures, as, for example, the emergence of multicellular creatures from single-celled organisms. In this sense, cooperation becomes as essential for evolution as is competition." (Nowak, May, and Sigmund 1995, 81)

### ***1.3.3 The Traditional Building Delivery Process***

#### **1.3.3.1 The Role of the Architect**

[A]rchitecture can be so pure, so elegant, when a single architect creates without outside interference, and...the opportunities to do so are virtually non-existent.

Dana Cuff

The presence of architects has been documented since the third millennium before Christ. The architect as a conceiver of buildings, a supplier of images for new structures has existed from the time that buildings of any substantial scale were erected. However, until recently only a small fraction of the total built stock ever involved architects. The skill of the early architects was seen to lie in their learning and in the gift of invention (Kostoff 1977).

In Western culture, the practice of architecture developed into a distinct professional activity in the late eighteenth century but subsequently established itself more solidly as result of the development of specialties

in building. Engineering as a separate activity occurred with the beginnings of modernism in the nineteenth century. The roots of the change lay in the industrial revolution with the rise of new scientific knowledge on the limits of traditional building materials and the development of new materials like iron and cast iron (Benevolo 1977).

With increasing technical innovation in the early twentieth century, more specialization was necessary and engineers developed areas of expertise in structural, mechanical and electrical engineering. Although engineers designed some early modern buildings, the architect took on the role of coordinator of the engineering specialties. In the late twentieth century as a result of even greater technical development, specialization has expanded further to the point where a complex building can employ the skills of up to thirty specialist sub-consultants and receive input from up to twenty regulatory or stakeholder bodies (Cuff 1992). Architects have largely retained their role as coordinators of these special sub-disciplines but the emergence of the project manager as the coordinator and leader of a project team is increasingly challenging the profession. Beyond the coordinator's role, the architect's contribution to the project has been reduced to that of a provider of aesthetics or 'form' (conceived of in a sculptural sense). The scope of the architect's role has been further eroded by the rise of the urban planner since the mid-nineteenth century (Benevolo 1977), the interior designer since the late eighteenth century (Rybczynski 1986) and more recently the architectural technologist (Architectural Institute of British Columbia Newsletter, May 1996). While this outcome may have been inevitable given the tendency of many architects to focus exclusively on the aesthetic aspects of design, it has led to the situation where the major concerns of the project manager (scope, quality, risk, budget and schedule) often become the sole driving force of the project delivery process (Duncan 1996). The traditional role of the architect as a member of a "profession", interested in and standing up for the common good, has become largely subsumed by the narrow imperatives of the client. Consequently concerns related to community well being or environmental impacts are seldom voluntarily considered. This has led to controlling mechanisms such as building codes, health-planning legislation, and

environmental protection legislation, all designed to protect the public interest. The role of the architect as the representative of the public interest has declined drastically since the early part of the century (Bender 1994).

Donald Schon summarized the general crisis in public trust of professional knowledge by citing a series of negative and unintended consequences due to the recommendations and actions of professional experts (Schon 1977). In the last decade this trend has continued and grass roots reactions against traditional professional expertise have become increasingly common. Schon also noted the crisis of confidence within the professions. Accelerating technological change has required unprecedented professional adaptability. Simultaneously both the body of professional knowledge and the expectations of society have vastly expanded. Consequently, the task facing the professions has become one of managing complexity (Schon 1977).

Design takes place when a person makes plans about the future environment. It is in the context of all the participants' interactions that a building emerges (Cuff 1992). Although I mainly discuss design as an individual activity, I also recognize and discuss design as a collaborative activity involving teamwork and the input of many actors in the building delivery process. All the aspects of design process described in the dissertation are relevant to all the actors. The emphasis that I will place on the role of the designer as an instrument of information processing and a generator of artificial constraints necessitates a change in emphasis from design as a solitary form-giving activity to one of design as the generation of adaptive responses to relevant economic, social and ecological constraints.

Many architects have disassociated themselves from economics and politics; the social forces that shape buildings. They have also disassociated themselves from the ecological consequences of building. In order to re-engage in these processes, I contend that architects must involve themselves in managing the project delivery process and engage their design skills in the *process* of creating a building as well as in designing

the actual fabric of the building (Dutton 1991). This engagement will help them understand and respond appropriately to a broader range of environmental constraints. I contend also that all participants in the project delivery process must broaden their design process to more closely follow evolutionary processes. I will elaborate on this in Chapter 2.

### **1.3.3.2 Description of the Existing Process**

The existing building delivery process involves many people who interact in fairly predictable ways according to well-established procedures. First, a need is identified. This can occur at an individual level, an institutional level or a community level. The need can be for a dwelling, a place of work, a hospital, a school, a subdivision or a commercial development. This need can be turned into a project by the party that has the need or by a third party (a developer) who determines that an opportunity for profit exists in fulfilling the need. These two basic approaches give rise to different imperatives on the part of the 'client'. In the former case, the client is directly interested in the end product as a means of meeting the need. In the latter case, the client is interested in the end product primarily as a means of making a monetary profit. However, in both cases the objectives are essentially confined to the provision of a facility that meets a need. The statement of need is usually confined to the immediate imperatives of the client. While some of the larger concerns related to the needs of the community (such as zoning and public safety) are addressed by planning controls and building codes, other concerns (such as public security) are either not made explicit or not addressed. Similarly, while certain undesirable environmental effects of the building (such as emissions) are controlled by legislation, others (such as energy use or sewage effluent) are either unregulated or not able to be addressed within the parameters of the project. Present environmental legislation related to buildings such as environmental assessment acts and waste management acts are mainly limited to controlling known by-products of industrial processes and mitigating site contamination and loss of biodiversity.

Once the statement of need is clear and the financial resources to address it are available, a client will contract directly with a professional or a series of professionals to develop a design for a building which

meets the need and responds to the legislative requirements of the community. This prime contract is usually either with a project manager, an architect, or an engineer. Recently alternative design/build contracting arrangements have been developed where the prime contract might be with a construction manager or a contractor. In either case, the prime consultant will then engage sub-consultants to provide the necessary range of professional expertise for the design of the particular facility being developed. Upon completion of the design and all the technical details and specifications necessary for the construction of the building, the project will be priced and constructed. In these arrangements, the client is seeking expert knowledge and advice as well as accountability and responsibility for an end product which meets the stated need in terms of quality, cost and time.

#### **1.3.3.3 Critique of Traditional Project Design Process**

“In the particular case of architecture, we encounter a paradox; the growing prestige of Architecture as an institution is offset by its social marginality and irrelevance. It is symbolically powerful and concretely powerless.”

Miriam Gusevich

The process outlined above has developed over a relatively short period of time in response to increasingly sophisticated societal demands for more refined products, the relatively conservative demands of financial institutions who lend capital for development, the more complex and readily available technical systems at our service and the public demand for more accountability from project developers. Just as clients have become more demanding in their requirements for fast, efficient and cost effective service, society has become increasingly concerned and vocal about responsible development. Communities want development that respects existing context and fits within their cultural and social milieu. At the same time, it is evident that pollution levels, energy and resource conservation and waste management are becoming critical to the health of global ecological systems (Brown 1995). This presents a paradox for designers who increasingly see themselves as caught in a double bind: being asked to do more for less.

Again at the heart of the paradoxical demand for both more sophisticated buildings and more accountability for their negative effects, is the dilemma of the Tragedy of the Commons (Hardin 1968). Participants in the system must act 'extrarationally' or outside the boundaries of their personal rational framework in order to deal with the paradox. Concepts such as trust, solidarity or conscience must be invoked. This is one aspect of the traditional role of a professional in society: an individual who will act in the interests of the public good (Commission on Post-Secondary Education in Ontario 1971). Unfortunately this aspect of the architectural profession has been largely eroded in the latter half of this century. Boyle (1977) has shown that this erosion occurred because of the rise of the large business-oriented architectural firm in America. One can also speculate that the present 'star' system with its emphasis on the visual aspects of a building has made a substantial contribution. The increasing emphasis on design theory as an intellectual, abstract reflection of literary theory has led to an overemphasis on avant-garde visual aesthetics as the key to success in the eyes of the professional architectural press and consequently in the eyes of most architects (Thomas 1997).

Being a partner of progress, capturing the essence of an age identified (or claimed) as fundamentally new, particularly one that is also the culmination of history, creates a great and dangerous freedom. The designer is able - in fact, is required - to create completely new standards by which to build and judge, values that because of the avant-garde must reject precedent (Thomas 1997, 258).

To be a part of the star system, an architect must lay emphasis on personal aggrandizement at the expense of larger ethical concerns. The internal constraints overpower the external constraints.

Whatever the cause, the reduction of ethical concerns has resulted in buildings which respond to the narrow, specific needs of the owner and the artistic needs of the designer, but largely ignore the larger requirements of the community and the ecosystem of which they are a part (Brolin 1976, Brown, Flavin, and Kane 1996).

One result of the increased complexity and higher stakes of the traditional project design and construction process has been an increase in litigation. Under threat of litigation, the players in the process develop strategies to position themselves favourably for the litigation thus undermining any initiatives for co-operation. This is a positive feedback loop and the ultimate result is to make the process more complex, more costly and less flexible. Recent efforts to introduce "partnering" to construction processes reflect the desire to overcome the inherent limitations of the paradox of the participants co-operatively working on a project while defensively protecting their position in future litigation.

Decision-making on a project tends to proceed according to a linear model. Handbooks of Practice such as that of the Royal Architectural Institute of Canada outline these steps. Usually, the site is selected first, then the building program is developed, often by a specialist programming consultant. Then the prime consultant, usually an architect, is engaged. The architect retains subconsultants: landscape, structural, mechanical and electrical, but then analyzes the site and the program and develops schematic designs without subconsultant involvement. Development permits are applied for and the design is checked by a municipal planner for conformance with planning and zoning regulations and other technical requirements. Often a design panel representing community interest is given an opportunity to review the design and make comments. The subconsultants are given the schematic architectural designs and asked to design their engineering subsystems to conform to it. Architectural, structural, mechanical and electrical working drawings and specifications will be developed with the various disciplines working in isolation. Landscape design work will often occur at the end of the process since it is viewed mostly as a separate 'add on'. The architect co-ordinates the specialist documents towards the end of the working drawings to ensure there are no conflicts. The building represented by working drawings and specifications is then priced competitively in a short period of time by general contractors who call on sub-contractors (up to twenty or occasionally more) to price their specialized sub-component of the work. The general contractor tendering the lowest price is awarded a contract and then co-ordinates construction of the work of all the sub-contractors within the terms

of the sub-contracts. A building permit is applied for and a building inspector checks that the design conforms to the building code and also follows up during construction to ensure that the building complies with the code. The delivery of the project takes place in the context of the many parties involved pressing for the maximization of their own interests (winning at litigation and incurring financial profit) while minimizing the risk of negative consequences (losing at litigation and incurring financial loss). Usually contractors will look for every opportunity to ask for extra recompense for work that is necessary but omitted in the contract documents or for changes to the scope initiated by the architect or the client.

The basic process can be complicated by the addition of cost consultants, interior design consultants, landscape architects, code consultants, elevator consultants, acoustic consultants, building management system consultants, disabled access consultants, scheduling consultants. The specialist consultants continue to grow in number as the process becomes more specialized. These specialist subconsultants are normally unaware of the basic parameters of a project and will be called in by the architect at specific points in the process to provide their particular expertise and will then have nothing more to do with the project. There is little emphasis placed on the specialists as a team and this attitude is perpetuated through the education of architects who are largely taught that they have sole control of the design decisions related to form. Thus the form arises from an impoverished set of constraints made up of the client's imperatives and the personal interests of the architect along with zoning and building permit regulations. The larger constraints of the ecology of the site, the energy and water flows, the cultural context, the community context and the neighbourhood context are rarely allowed to become part of the forces affecting 'form-making'. The narrowness of the constraints that the architect responds to leads to buildings that lack 'fit' and are not well-adapted to their real environment.

Not surprisingly, this process results in lack of shared objectives, contradiction, confusion, hasty decision-making made in isolation from the complete project parameters, and an atmosphere of distrust. However, in certain ways the process works within the narrow confines of the objectives of the individual participants. In

the end the client has a building which more or less meets his needs, his budget and his schedule. The consultants are paid for their work and occasionally derive professional satisfaction and community recognition from it. The contractors and their employees also get paid for their work and occasionally derive satisfaction from their accomplishment.

There are three major external constraints on the existing process which end up as peripheral to the designer: the users of the building who usually have no input into the development of comfort standards; the community into which the building is inserted; and the ecosystems which provide the resources for the building materials, the inputs for their continued operations and the sinks for their by-products.

#### **1.3.3.4 Success in the Product**

The existing project design process is judged to be successful if the building meets the needs of the client and is delivered on time and within budget. An additional measure of success is the winning of awards for the product by the architect or the developer/owner. Architectural competitions are judged by respected members of the profession who are immersed in the shared value system that has led to the present dilemma.

I adopt the position that these are necessary but not sufficient measures of success and that broader criteria are necessary. These criteria are framed by the contribution that a building can make to the health of the users, the community and the natural environment. They are measures of the 'fit' of a building to its environment. "A structure or organism is fit only insofar as it is adapted to its environment and contributes in some useful way to the organism or system that created it or of which it is a part." (Cziko 1995, 8) I develop a set of indicators for 'fit', based on the three imperatives of sustainable development: economic, socio/political and ecological. The building design process has implications for these imperatives at various levels within the global system. The indicators are developed in detail in Appendix 1.

## 1.4 The Necessity for Environmental Links

This way of thinking and operating, which has shown its efficacy over a long period of time, is now beginning to look simplistic and myopic. The continuous fracture of circular and cybernetic structures and their substitution by linear sequences cannot continue forever. The links that have been neglected are reappearing as problems. The grand project of the simplification of reality is showing its limitations. The systemic complexity that was thrown out the window is entering now through the front door.

Enzio Manzini

A systems approach to sustainable design involves considering the various agents interacting in the world as systems. General principles from systems theory can be used to make inferences about interactions between the systems under consideration. I refer to systems theory not only to augment our knowledge of the impacts of the design *product* on natural systems but also to inform the system of design *process*.

Linearity in a system is a relationship between two variables (say  $x$  and  $y$ ) that is proportional for all values of the cause ( $x$ ) and the effect ( $y$ ). The effect of changing two or more control variables (say  $x_1$  and  $x_2$ ) together is the sum of the effects of changing them independently. This shows on an  $x/y$  graph as a straight line. If the heat is turned up under a kettle then the water will get hotter proportionately to the amount of energy supplied. Doubling the energy will double the rate of increase in the temperature. If air pressure as well as temperature is varied then the effect on the temperature is the same as the sum of the effects of changing these variables individually. The effect of each control variable is independent of the effects of any others. Linear systems do not exhibit chaos or critical behaviour (Clayton and Radcliffe 1996, 26).

The design process while often described as linear is not in actuality linear. Small changes in one control variable can have disproportionately large effects. And combinations of control variables have even more disproportionate effects. This is true at both the level of the internal decision-making process and at the level of the product of that process. A seemingly insignificant event such as asking a design student to recall a visit to a museum can have an enormous effect on a design proposal or it can have none at all. The

language of the design studio is filled with phrases that reflect this phenomenon. Professors will discuss 'turning up the heat' or 'getting the students out of the mire'. Donald Schon talks about design as a "process of continual adjustment in the service of maintaining a sense of constancy...sometimes, however, there are surprises...they are anomalous, and if they are noticed, they yield uncertainty - meaning not merely that one cannot predict for sure what will happen but that, at least for a time, one cannot make sense of the situation" (Schon 1985, 25).

Non-linear consequences show on an x/y graph as a curved line and their growth typically exhibits an s-curve. Nonlinearity causes small changes on one level of organization to produce large effects at the same or different levels. Nonlinear systems also exhibit criticality where the qualitative behaviour of the system changes radically at a critical point. In physical systems these points are called phase transitions or thresholds. We are not able to easily perceive and consider nonlinear consequences using traditional positivistic methods.

Designers must refocus on a wider set of constraints, make the links to the larger system which the design will impact and understand the potentially non-linear effects of their design decisions. I quote John Chris Jones at some length here in order to introduce the notion of a different role for designers. It is interesting to note that Jones pioneered the study of design methods in the early sixties and has now abandoned that approach having concluded that it is unproductive:

"What stops us acting together as a context for our works, adapting freely to what we discover in doing what we do? The blocks are product-thinking, function-fixing, role-fixing, cost-reducing, and our identification of ourselves with these things instead of with our thoughts, feelings, minds, common-sense awareness of what is needed but what we are not paid to do. All this leaves us over-adapted to the status quo (which we identify with self, with security, when in fact it is what destroys the self, the being, the joy of living). That is why, I believe, we seem to lose the adaptiveness, the biological adaptiveness, with which we are born." (Jones 1988)

### **1.4.1 Evolutionary Theory**

In order to explore ways for designers to make links to the larger systems, I consider the project team, the designer and the design activity as evolving adaptive systems. Two important and connected phenomena in all natural systems are evolution and adaptation (Clayton and Radcliffe 1996, 28). Evolution occurs whenever there is reproduction and competition for finite resources. The study of evolution is concerned with how different plants and animals have become adapted to different conditions. Darwin put forward the idea of natural selection as the mechanism by which change occurs. Small variations that occur during reproduction of the organism will lead to variation in individuals and those variations that allow an organism to survive in the particular conditions of its environment will lead to reproduction with that trait being passed on to subsequent generations. The key idea is that of natural *selection* occurring after random *variation* during replication. The less 'fit' variations will not survive and thus will not be passed on to subsequent generations. This is known as survival of the fittest.

Hooker (1995) shows how a systems perspective for populations and individuals implies a certain displacement of a simple Darwinian variation-selection-retention process as the self-sufficient basis for evolutionary theory but notes that the systems perspective itself is compatible with orthodox neo-Darwinism. "Once cells, individuals, biological communities, and so on are all understood as complex, highly interactive dynamic systems there is no longer an obvious causal (i.e. dynamical) basis for drawing any sharp difference in kind between them" (Hooker 1995, 55). Similarly, thoughts, design moves, and design proposals are highly interactive dynamic systems as are designers, clients and communities. Modeling the evolutionary dynamics of these systems will help us understand them.

### **1.4.2 Complex Adaptive Systems**

Complex adaptive systems (CAS) display collective behaviour of many basic but interacting units which are endowed with the potential to evolve in time. "Their interactions lead to coherent collective phenomena, so-called emergent properties that can be described only at higher levels than those of the individual units" (Coveney and Highfield 1995, 7). While some basic models of CAS exist, much recent research has been focusing on the modeling of emergent properties. "A well-conceived model will exhibit

the complexity, and emergent phenomena, of the system being modeled, but with much of the detail sheared away" (Holland 1998, 9).

For complexity to emerge, two ingredients are necessary. The first is an irreversible medium in which things can happen: time. The second is non-linearity. The richness of the interactions allows the system as a whole to undergo spontaneous self-organization. Complex systems are spontaneous, disorderly and lively. The concept of complex adaptive systems allows scientists to study the world in a way that is not possible with traditional scientific linear, reductionist thinking (Waldrop 1992). "[E]mergence in rule-governed systems comes close to being the obverse of reduction" (Holland 1998, 8).

Design displays non-linear and emergent characteristics and may be considered a complex adaptive system. The basic, interacting units of design process and their control variables will be established in a subsequent section and described in more detail in Chapter 2. One can readily describe design proposals that are the result of a design process as emergent phenomena. It is self evident that design occurs in the irreversible medium of time and I have established the non-linear nature of design in the previous section.

### **1.4.3 Hierarchies**

A hierarchy is a group of things arranged in successive orders or classes, each of which is subject to or dependent on the one above it (Landau 1968). Herbert Simon (1979) terms this etymological definition a 'formal hierarchy'. He distinguishes it from a more general definition of hierarchic system as one that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure. I use Simon's terminology. Throughout the dissertation I refer to levels of hierarchies in the different systems under discussion. For example, in the Tragedy of the Commons discussion, the resolution of the paradox of care for the commons comes from moving the frame of reference for decision-making from the level of the individual to the level of the group. Similarly, in the discussion of the critique of contemporary architecture, I make the point that the frame of reference for design decision-making must be brought to the next level of the system under consideration i.e., the community and ecosystem into which the design product is to be inserted.

Hierarchy theory is used to analyze the case studies. Hierarchy theory addresses the challenge to modern science of interpreting and integrating the data that it deals with. It is “less a theory to be tested than a position of self-consciousness of the investigator as to how the pursuit of understanding proceeds...[it] lies between perception and learning to focus on observation...prior learning is invoked to structure new perception, and new perceptions are used to advance learning in the form of theory construction and modification” (Ahl and Allen 1996, 13). The approach is to identify problems that rest on conflicts of definition that generate internal inconsistency. By clarifying the observation process, conflicting levels of analysis may be clarified. The ‘why’ of a phenomenon comes from the level above (the context), the ‘how’ of a phenomenon comes from the level below (the content).

#### **1.4.4 Creativity Theory**

In both evolutionary and creative exploration we encounter patterns and lines of development (strategies) that emerge under selection. John Holland

Arthur Koestler, in The Act of Creation, developed the theory that creativity is merely the highest manifestation of a phenomenon which is discernible at each successive level of the evolutionary hierarchy. It is “an actualization of surplus potentials” (Foreword by Sir Cyril Burt, Koestler 1964). Design is the activity that actualizes potentials. Some authors have suggested that the activity of science is a subset of the activity of design (Glanville 1998, Wilson 1998). Just as design is a creative activity, so is science.

In addition to Koestler, there are other authors in creativity and aesthetic appreciation whose work is particularly relevant to my propositions. Berlyne (1971) has carried out work in experimental aesthetics. (Amabile and Stubbs 1982) have researched the measurement and promotion of creativity amongst schoolchildren. Rothenberg (1979), a psychiatrist, developed a theory of creativity based on oppositions called Janusian and homospatial thinking. Rose (1992), also a psychiatrist, developed a theory of aesthetic appreciation based on the balance of primary and secondary processes. Lastly, de Bono (1985) and Adams (1986) are practitioners and action researchers in techniques that enhance creative potential.

## 1.5 The Origins of the Pagani Framework

### 1.5.1 *Theory and Practice*

As the product of both an apprenticeship program and a university program in architecture, I have always been aware of and valued the interplay between theory and practice. In over thirty years of involvement in the practice, learning and teaching of architecture I have held the ideal of practice informing theoretical beliefs and theoretical beliefs informing practice.

Mainstream architectural theory since the seventies has developed into position based and abstract rhetoric, largely drawn from literary theory. The effect on architectural practice has been to encourage a superficial borrowing from theory and to express it in shallow stylistic terms. Thus, in the last thirty years we have rapidly moved from modernism to post-modernism to deconstructivism, each successive style in its own way offending users of the buildings and the communities into which they are inserted.

Evolutionary theory, creativity theory and design process theory have deeper relevance for architecture. These process theories might seem largely irrelevant to the practitioner who works in a world of pragmatic and urgent decision-making, hemmed in by the constraints of clients, time, budgets, planning controls and regulations. As Donald Schon has remarked, “the theory that actually governs [a practitioner’s] actions is his theory-in-use, which may or may not be compatible with his espoused theory” (Schon 1977). If process theory could be presented to practitioners in a framework that opened possibilities for more rewarding practice then it is likely it would be embraced with alacrity.

As I practiced and taught, I came to understand the gap between the theories of process and the theories-in-use and sought to develop through reflection-in-action (Schon 1977) grounded theory that could be usefully applied in teaching and practice. Over time, I developed a basic model of the design process which was rooted in my everyday experience. This model conceptualized a series of concrete observations about ways of triggering those moments when one feels a “click” of fit between the problem under consideration and the solution being proposed. In ‘doing design’ there are moments, usually few and far between, where one experiences a sense of “flying” above the nitty gritty details of the issue at hand, a sense of excitement at discovering a synthesis or a reconceptualization of the parts. These moments are

what keep the designer entranced by a profession which otherwise offers long hours, financial instability, little positive feedback and major professional liability. I sought to expose the conditions underlying these 'islands' of discovery so that the process could be both taught and enhanced under conditions of practice. It seemed that the 'clicks' occurred at those moments when I switched between one mode of thinking and another, e.g. at the point when after analyzing site contours I 'saw' that the conference room could slide under the offices. Koestler (1964) in his book The Act of Creation suggests that creativity occurs when two previously disassociated ideas intersect to form a new association. He points out that in humour this phenomenon is accompanied by "a massive and sharply defined response on the level of physiological reflexes." I believe that the experience of the "click" in design and the accompanying feeling of excitement is exactly like that of the laughter response upon 'getting' the joke. Grossman and Wiseman (1993) propose that the imagining of potential future states is essential for creativity and it is achieved by "the energy of activation" (which is the additional boost of energy required to start two chemical reactants interacting to form a new entity). This is the catalyst that I refer to as a control parameter. Grossman and Wiseman also believe that joy is the result of creativity and not the motivator.

Donald Schon has noted the importance of oscillation in his study of design studio learning. Professor Quist has a dialogue with his student Petra about her design: "Quist has been able to give Petra reasons for her intuitions. Now he makes a basic design principle explicit: attention must oscillate between the "whole" and the "unit", the global and the local. Under the metaphor of designing as speaking, Quist contrasts her "stuttering" with his own smooth delivery." (Schon 1985,43) Embedded in this is the notion that professional expertise comes from speeding up the rate of oscillation through practice. Later Quist also points out the need for the designer to oscillate between involvement and detachment (ibid., 49)

From my observations in teaching, it seems that the best student design work occurred when:

- in addition to good contextual *information*, novel information was introduced into the problem under consideration; e.g. in a studio design problem of designing a space for oneself when the students seemed 'stuck' the professor added a requirement to fold in nine yards of red fabric to the space. Most of the resulting designs were transformed from standard conventional responses into imaginative and

delightful proposals that surprised even the students who produced them. The students who were able to synthesize this information and go beyond their analysis of the given contextual information produced innovative work.

- the students were *inspired* by the task; when students were motivated beyond obtaining good grades their work was superior. They tackled their work with both passion and intellect. The best students were able to produce many varied design moves yet still focus their design strategies coherently on a goal.
- when feedback in the 'crit' format was pointed and critical; the time-honoured hanging of the design for criticism by outside jurors brings the students an outside view of the work which provides valuable feedback and helps them set new *intentions* for the next iteration. Superior work was produced by students who selectively used precedent and transformed it to suit the current project conditions.

From these three observations, I decided that the following operations were critical:

- synthesis and analysis of accepted basic contextual information as well as novel contextual information
- divergent thinking and convergent thinking developed from the subconscious and the conscious mind
- critical feedback on precedent which promotes reflection on intuitive design moves to inform subsequent moves

Through subsequent analysis I observed that divergent/convergent thinking seemed to be of a different order than the other two operations. It seemed that divergent thinking was a definite stimulus to creativity. This intuition was confirmed by reading of recent creativity literature (Ebert II 1994; Daniels-McGhee & Davis 1994; Grossman & Wiseman 1993; Rickards 1993). From this insight I looked for other operations which seemed to result in creativity and developed a second set of operations which seemed more active in promoting creativity. In systems terminology these are agents of change.

I call the basic conditions identified above *information*, *inspiration* and *intention* and I propose that they are change agents at three levels in the design process system. The levels form the z axis of the proposed framework outlined in FIGURE 2. In systems theory the *control parameters* or control variables are those which maintain system integrity or performance under changing demands. The three basic conditions interact non-linearly, i.e. the combined effect of changing two or all three is not additive. The effect can be disproportionate to the cause. Significant change can occur as a result of small and seemingly insignificant cause. This is consistent with evolutionary theory and thus also with CAS.

Each condition emerges from oscillation between two sets of operations which form the x and y axes of the framework. The x axis operations are a continuum between the units of *variation* (in systems terminology a *change agent*) and *adaptation* (a *conservation agent*). The y axis operations are a continuum between the units of *integration* and *differentiation* (in systems terminology *boundary-breaking vehicles*). These operations work interactively to dynamically provoke the design process. They are the mechanism by which the designer achieves a broader frame of reference (boundary-breaking). Through change and conservation the conditions are created for the boundary-breaking vehicles to operate. Through the boundary-breaking vehicles the system is enabled to break through the boundary that separates the inner from the outer environment. In this way the system attains a new level of integration and an irreversible shift takes place. This is what I have called a 'click'. The foregoing components form the basis for the proposed alternative project design process framework. They are developed in Chapter 2.

By developing a framework for a project design process I intend to provide practitioners with a tool for use in their daily decision-making. As the complexity of the constraints on a project increase, the designers have more need of a navigational aid that is nonspecific but universally applicable. I aim to develop a tool that is easily taught, directly applicable and seen as useful. I aim too, to bring to consciousness the critical role which owners, project managers, subconsultants and the public have in the project delivery process and to make explicit the changes that will result from use of the design process framework.

Since evolutionary processes and the processes of complex adaptive systems are relatively well understood, I look to them for applicability in project design process. I show that design can be modeled as a complex

adaptive system and that creativity is essential, indeed inevitable in evolution and design. I show that by developing “boundary breaking” skills, designers will be able to adopt a broader frame of reference and design in response to the larger context of the environment.

The research undertaken will ascertain: the usefulness of the framework as a tool for designers; whether use of the framework results in buildings which are more creative and/or more adaptive, i.e. which ‘fit’ the environment better and; whether oscillation between the change and conserving agents leads to creative breakthroughs.

A theory of complex adaptive systems is crucial to our understanding of ecosystems. Until we understand the ‘lever points’ of a system, our attempts to balance extraction of resources against sustainability will be naive. I take the point of view that one way to approach understanding is to use the ‘design’ concepts presented in this dissertation. We are a part of the ecosystem that we are adapting for our own purposes. By maximizing creativity as I present it here, I assert that we will co-evolve with the ecosystem to which we are adapting as opposed to our present practice of attempting to control the ecosystem resulting in unintended consequences (or emergent properties) that become apparent downstream.

The dissertation is divided into two main parts: the first (Chapter 2) is an in-depth examination of relevant theory and the second (Chapters 3 and 4) is a description of illustrative examples that are aimed at testing the theory. It is recognized that ideally a holistic approach would be undertaken. However as this was not possible for financial reasons, case studies that addressed the overarching hypothesis were used to move the theory closer towards practice.

## **Chapter 2**

# **The Art of Fugue, Feathered Wings**

### *Design as an evolutionary complex adaptive system*

The Art of Fugue and the St. Matthew Passion were, for the evolving organism of human thought, feathered wings, apposing thumbs, new layers of frontal cortex.

Lewis Thomas

## **2.1 Introduction**

While many authors have linked complex adaptive systems (CAS) or evolutionary theory with human social and cognitive processes there is less literature specifically in relation to design process and particularly architectural or engineering design process as a CAS. Consequently while the review of the literature focuses on design process as a CAS it also examines the literature on creativity as an evolutionary process and on computation process as a CAS. My central contention is that contemporary architecture is maladapted to its ecological context. I propose that a more evolutionary design process will focus the attention of the project team on the natural systems within which they are inserting the design. The control parameters of information, inspiration and intention (as outlined in the previous chapter) will influence designers to respond to the external constraints of the ecological context within which the design product will fit. The result will be more adaptive buildings which more closely fit their context and which address the systemic nature of buildings as artificially created elements of natural systems. The construction and operation of buildings uses natural resources and also produces waste streams and emissions that impact natural systems. Designers must be enabled to design products with an understanding of the upstream and downstream environmental effects of their decisions and an understanding of the interaction of the design product with its ecological context. In order to do this, they need appropriate information, inspiration and

intention. Existing design products are generally 'fit' in relation to economic issues as presently defined by clients and at least partly 'fit' in relation to social issues. So, I would contend that information, inspiration and intention are present for these two areas. In relation to ecological issues design products are generally minimally adequate. If the proposed design process framework is to be effective it must be shown that it functions to effect a positive change in the design product in relation to ecological issues. Information, inspiration and intention related to ecological issues must be brought into the process.

## **2.2 Review of the Literature**

### **2.2.1 Introduction**

I review in detail the literature that discusses design process (or a particular aspect of it) as a complex adaptive or evolutionary system. I note the content that is directly relevant to my work and begin to pull out the strands of the proposed design process framework.

Bateson (1972), Berlyne (1971), Bogdan (1997), Capra (1996), Churchland (1996), Cziko (1995), d'Aquili & Mol (1990), Dennett (1995), Dyson 1997, Edelman (1992), Gell-Mann (1994), Gnuse (1990), Harth (1993) Kelso (1995), Krohn, Koppers, et al. (1990), Lakoff (1987), Penrose (1990), Rachels (1990), Smuts (1926) and Waddington (1977) all address cognition or aspects of it as CAS. Specifically related to architectural design and CAS, Kroll (1987) discusses changes to the process of project delivery (industrialization of components and involvement of the community) which he argues will result in better architecture. French (1988) writes mainly about how engineering design products can mimic natural form and structure through adhering to the structural principles of nature. Bullock, Denham, et al. (1995) discuss the application of the genetic algorithm to an engineering design by computer.

Simon (1969) and Jantsch (1975, 1980) examine design process in depth as a complex adaptive system.

Creativity is considered within an evolutionary context by Goertzel (1993); Campbell (1960); Finke, Ward, et al. (1992); Gregory (1987); Gruber & Davis (1988); Grossman (1994); Isaksen, Puccio, et al. (1993); and Kantorovich (1993). Creativity as a phenomenon has been covered in depth by Arieti (1976); Boden

(1990); Koestler (1964); May (1975); Rose (1992); Rothbart (1972); Rothenberg (1979); and Runco (1994).

Several authors have recognized and discussed passionately an ecological basis for design products (Lyle 1994, Thayer Jr. 1994, Todd & Todd 1984, Wann 1990) but have not made the extension to design process.

In computation literature some authors seek analogies between human cognition and computer applications (Brink & Haden 1989, Gregory & Marstrand 1987, Hofstadter & the Fluid Analogies Research Group 1995, Holland 1995, 1998, McCorduck 1979). Some of this literature is relevant to the study of the design process. Holland's concept of the genetic algorithm is particularly pertinent.

### ***2.2.2 Design as a Science of the Artificial***

In 1969, Herbert Simon wrote the seminal book on design science, The Sciences of the Artificial. In it, he lays the foundation for a theory of design. He makes a distinction between natural science, which seeks to "make the wonderful commonplace: to show that complexity, correctly viewed is only a mask for simplicity; to find pattern hidden in apparent chaos" (Simon 1969, 1), and artificial science. Natural science deals with organisms, inanimate matter and their processes. Artificial science deals with artifacts and their processes. He sets the boundaries for an artificial science as:

1. artificial things are synthesized by humans
2. artificial things may imitate appearances in natural things while lacking the reality of them
3. artificial things can be characterized in terms of functions, goals and adaptation
4. artificial things are often discussed, particularly when they are being designed, in terms of imperatives as well as descriptives

An artifact can be viewed as an 'interface' between an inner environment, the substance and organization of the artifact itself, and an outer environment, the surroundings in which it operates. The advantage in this view is that the behaviour of an artifact can be predicted from knowledge of its goals and its outer

environment with minimal assumptions about the inner environment. Also, the prediction of whether an artifact will achieve a particular goal is dependent on only a few major characteristics of its outer environment and not on the details of that environment. "A science of the artificial...would depend on the relative simplicity of the interface as its primary source of abstraction and generality" (ibid., 9). This leads Simon to the view that the human behavioural system is quite simple and that the apparent complexity of a system's behaviour over time is largely a reflection of the complexity of its environment. For Simon, humans, as well as human artifacts, are adaptive systems and he believes that there are only a few 'intrinsic' characteristics of the inner environment (brain) of thinking man that limit the adaptation of his thought to the shape of the problem environment (ibid., 26). Therefore Simon turns to physiology for an explanation of the limits of adaptation. He believes that as our knowledge increases, the relationship between physiological and information-processing explanations will become just like the relation between quantum-mechanical and physiological explanations in biology. They are two linked levels of explanation with the limiting properties of the inner system showing up at the interface between them. I am exploring the intrinsic characteristics of the limiting properties. For Simon design is "the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. Schools of engineering as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design" (ibid., 55). As Simon develops his science of the artificial it becomes apparent that he has a limited view of how design can be improved. He believes that more efficient search techniques in the generate-test cycle will lead to better design and he relies on the computer as the appropriate tool for this task. It has become apparent in retrospect that this efficiency approach has proved to have limited value. Simon does, however, point out that the design of complex systems such as buildings or cities might have variety as a desirable end and suggests that city planning might be better organized if it were to have members of the community give input in order to provide an opportunity for that variety to be generated. My work accepts Simon's basic precepts but extends and elaborates his view of design.

### **2.2.3 Design as an Evolutionary Process**

In Design for Evolution, Jantsch (1975) attempts to explain the contribution of the nonrational to successful design and to explore the dynamics of cultural change. He makes the point that efficiency of information processing can never fully explain the successful 'designer'. The book is an attempt to explain the contribution of the non-rational to this success and to explore the dynamics of cultural change.

According to the dualistic view of Western thought, evolution and design are different. Design is seen as an ultimately futile process of pushing uphill against the downward tide of randomness and entropy. For Jantsch, advances in the field of nonequilibrium thermodynamics (in particular the principle of order through fluctuation) point the way to overcoming this apparent duality. Jantsch attempts to extend these advances not only to human systems but also to human knowledge systems, including the development of human consciousness and the human design process. For Jantsch, physical systems, human systems and mind systems all exhibit non-random behaviour and mutation toward new dynamic regimes whenever they become "stifled by the debris of past entropy production" (Jantsch 1975, xvii). Jantsch proposes that the same kind of energy carries evolution in all domains - whether it appears in the form of "physical, vital, psychic, creative, or motivational energy or in the form of matter, information, ideas, consciousness, complexity, or mind" (ibid., xvii). Further, even while there is no hope of a one-sided resolution to the dualistic tension between opposites, that tension constitutes the energizing factor that keeps the human system in continuous motion. Such a dynamic view focuses on self-organizing processes and their interaction as they unfold in continuous feedback linkage to their own origins. Therefore, in human systems communication is key and resonance is the most important basic principle. "It is the old Chinese image of *Tao*, the right way, between the two opposing forces of yin and yang - the feminine and the masculine, the passive and the active, dark winter and bright summer" (ibid., 5). Subsequently, in 1980, Jantsch developed his ideas in The Self-Organizing Universe. Evolution is usually considered as a process of adaptation and survival, but Jantsch points out that the environment to which life is adapting also evolves and adapts. "To-grasp this co-evolution in a non-dualistic perspective required the development of a paradigm capable of dealing with self-transcendence, the reaching out beyond the boundaries of one's own existence, the joy of creation." (Jantsch 1980, xiii) The one-sided application of the Darwinian

principle of natural selection can lead to an image of 'blind' evolution, a process of chance and necessity acting in sequence (Monod 1972). Jantsch adopts the view that chance and necessity are complementary principles. Necessity is introduced by the system constraints that are themselves the result of evolution and this idea is important to design. If designers choose to accept inappropriate constraints then the necessity of the response to them will result in the product being maladapted.

In my own experience, the system constraints attended to by the designer are crucial to the design product. It is lack of attention to the important constraints of the ecological system into which a building fits that leads to wasteful and destructive practices. I believe that attention to economic, social and ecological constraints during design leads to well adapted designs. I also believe that novel constraints can 'push' a design to a new level of synthesis. "People often claim that talk of 'rules' and 'constraints' must be irrelevant to creativity, which is an expression of human freedom. But far from being the antithesis of creativity, constraints on thinking are what make it possible. Constraints map out a territory of structural possibilities which can then be explored, and perhaps transformed to give another one" (Boden 1990, 82).

Because of this complementarity between the system and its constraints, I accept Jantsch's view that biological, sociobiological and sociocultural evolution appear as linked by homologous principles (i.e. principles linked through their common origins) and not just by analogous principles (formally similar) principles. Building on Ilya Prigogine's work in non-linear thermodynamics of irreversible processes, Jantsch proposes that there is an ordering principle called *order through fluctuation* which describes the evolution of a system to a new dynamic regime. The physical-chemical reactions discovered by Prigogine represent the manner in which a system copes with increased energy and matter penetration in a system by way of exchange with the environment. This coping gives rise to the self-organization of stable structures called dissipative structures. The name comes from the fact that these structures maintain continuous entropy production and dissipate the accruing entropy as part of a continuous energy exchange with the environment. Rather than a statistical measure of the total energy share of a system, a dissipative structure is characterized by the rate of entropy production of the exchange with the environment, i.e., the intensity of energy penetration and conversion. "With the help of this energy and matter exchange with the

environment, the system maintains its inner non-equilibrium, and the non-equilibrium, in turn, maintains the exchange processes. One may think of the image of a person who stumbles, loses his equilibrium and can only avoid falling on his nose by continuing to stumble forward." (ibid., 31) Jantsch distinguishes between two types of systems: structure-preserving systems and evolving systems. Structure preserving systems are at their equilibrium or approach it irreversibly. Evolving systems are far from equilibrium and evolve through an open sequence of structures. Structure has traditionally been understood to mean spatial structure, but Jantsch extends this notion to that of a space-time structure, which includes the function of the system, and thus also its organization and its relation with the environment. Whereas structure preserving systems are: static; in equilibrium; have no function; and are generally isolated from their environment, evolving systems have: dissipative self-organization; far from equilibrium structure; self-referential function; non-equilibrium internal states; and an open relationship (continuous balanced exchange) with their environment (ibid., 34). By this definition, both humans and their mental processes are evolving systems and fluctuations play a decisive role in the emergence of new order or qualitative change in the dynamic existence of these systems.

Information plays a key role in the discussion of order. Information is composed of two complementary aspects: novelty and confirmation. Pure novelty (or uniqueness) does not contain any information. It stands for chaos. Pure confirmation does not bring anything new. It stands for stagnation or death. In between there must be a finite information maximum, depending on the complexity of the exchanged information (including the complexity of the sender and receiver).

FIGURE 3 shows Jantsch's diagrammatic conception of a dissipative structure. Novelty is transformed into order and the system moves towards confirmation and ultimately equilibrium. One hundred percent confirmation corresponds to thermodynamic equilibrium. Equilibrating structures tend toward maximum confirmation. Dissipative structures may evolve through states characterized by maximum novelty (instability thresholds) to new states characterized by a balance between novelty and confirmation: autopoiesis. In the transition to autopoiesis, the entropy production reaches a maximum. In autopoiesis itself, the entropy production tends to a minimum. Autopoiesis is the characteristic of living systems that

enables them to continually renew themselves and to regulate this process in such a way that their integrity is maintained. An autopoietic structure results from the interaction of many processes. I understand autopoietic and dissipative structures to be the same phenomena. In FIGURE 3, one hundred percent confirmation corresponds to a system in thermodynamic equilibrium. Pragmatic information is zero since there is no possibility of any directed effect. One hundred percent novelty is the instability phase in which stochastic (random or intrinsically unpredictable) processes cease to confirm the old structure and have not yet established the new structure. In between is the balance between novelty and confirmation: the domain of autopoiesis. After the formation of an autopoietic structure the system oscillates in a balance between novelty and confirmation and has to 'work' only to the extent that novelty has to be coped with. I call the processes that operate in this dynamic regime of coping *the boundary-breaking vehicles*. I call novelty and confirmation *the change and conservation agents*. These are the means by which the system boundaries are permeated. I propose they are the means for achieving creative leaps or 'clicks' in design. I will use FIGURE 3 as a basis for a model of the dynamics of the design process framework.

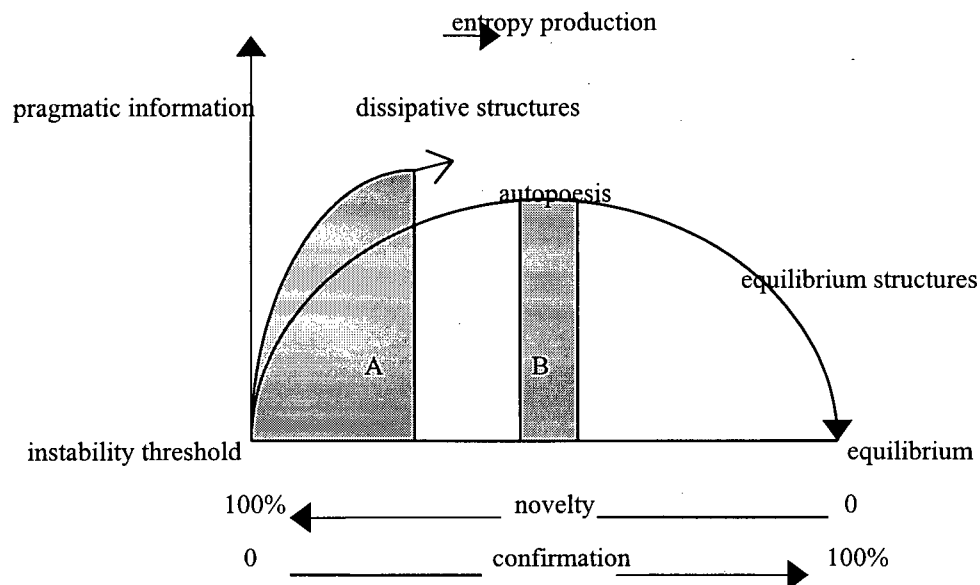


FIGURE 3 ORDERING PRINCIPLES IN NONEQUILIBRIUM AND EQUILIBRIUM STRUCTURES

(Jantsch 1980, 52)

When an autopoietic structure comes into being, new information increases and the system moves towards confirmation from novelty. The significant input of energy required for the formation of the structure produces or dissipates entropy. The source of this energy in design should be made explicit so that it can be readily harnessed. Immediately beyond the 'chaos' of the instability threshold maximum entropy production is needed to attain confirmation. Area A in 3 has to be won very quickly by hard work and thereafter is maintained by oscillation in balance between novelty and confirmation. As greater amounts of novelty enter the system it moves further to the left and drops down into greater differentiation and ultimately to 'chaos'. Now it must work hard to maintain balance by pushing back to the right through a reintegration of the novelty into the previously confirmed structure. Novelty is continuously transformed into confirmation through the process of integration. Jantsch draws the conclusion that cognition is a circular process between a human and its environment. Unfamiliar *patterns* in the environment (novelty) force a reintegration of previously adopted structures of knowledge and move a person to new levels of understanding of the environment. Without the recognition of the new patterns the person will tend to migrate to greater confirmation with more differentiation. Without a stimulus (from a control parameter) to attend to the novelty in the environment the person will become 'stuck' in habitual ways of dealing with situations and will be unresponsive to change. People who are more attentive and responsive to new patterns and can reintegrate them into their existing structure of thought are able to adapt to change.

I draw on Jantsch's diagram in order to develop my own ideas about the design process. I propose that the design process has an autopoietic structure balancing between the *integrative* and the *differentiative boundary-breaking vehicles*. When the interaction between these modes of expression increases through the action of a *change agent* the design is pushed to a new level of complexity. This new level of complexity is then stabilized by a *conservation agent*.

In FIGURE 4 on page 46, I show a hierarchy of three levels of control parameters (the process by which a system maintains its integrity under changing conditions) for four different systems: complex adaptive systems, living systems, social systems and design systems. Each level is described in terms of its conserving agent, its boundary-breaking vehicles and its change agent. Each level is a necessary but not

sufficient condition for a mature and well-functioning system. In the design system the parameters are those of information, inspiration and intention. Intention is the top level of control and has the prime role in directing the design toward specific goals and objectives. Inspiration is secondary and has the role of providing the drive to reach the goals. Information is tertiary and provides the material for which the other two levels provide the operation and the motivation.

The description of the process of formation of dissipative structures also maps neatly onto a description of the process of the formation of new paradigms in a discipline described in *The Structure of Scientific Revolutions* (Kuhn 1970) and in FIGURE 4 I show this process in brackets under social systems.

With this self-reflexive image of the mind, Jantsch brings into play the idea that anticipation brings about the dual notion of expectation (anticipated experience) and active goal-setting as the creative design of the future. These are the control parameters I call *inspiration* and *intention*. "Mind becomes a creative factor not only in image-forming, but also in the active transformation of outer reality" (ibid., 164). In this view the cognitive mode that forms structures and lets them evolve is associative rather than sequential. Dreams represent an important form of mental emancipation from the outside world by the self-reflexive mind. In the model I develop here, dreams and other ways to access internal associative mechanisms (*primary process* mechanisms) become tools with which to enrich the design process. Ultimately for Jantsch, "creativity is nothing else but the unfolding of evolution" (ibid., 296).

	COMPLEX ADAPTIVE SYSTEMS (general case)	LIVING SYSTEMS	SOCIAL SYSTEMS	DESIGN SYSTEMS
boundary-conservation agent [B]	heredity	genes	memes	genes (knowledge) D
boundary-breaking vehicles [ $\alpha$ & $\beta$ ]	crossover	female & male	inheritance & innovation	synthesis & analysis $\alpha$ & $\beta$
CHANGE AGENT [C]	VARIATION	MUTATION	EXPERIMENT	INFORMATION C
boundary-conservation agent [B]	adaptation	resilience	tradition (theory)	Motivation D
boundary-breaking vehicles [ $\alpha$ & $\beta$ ]	emergence & selection	environment & phenotype	collective & individual	primary & secondary $\alpha$ & $\beta$
CHANGE AGENT [C]	NOVELTY	DISTURBANCE	REBELLION (ANOMALY)	INSPIRATION C
boundary-conservation agent [B]	confirmation	speciation	culture (paradigm)	Operation D
boundary-breaking vehicles [ $\alpha$ & $\beta$ ]	self-organization	chaos & determinism	observation & criticism	intuition & reflection $\alpha$ & $\beta$
CHANGE AGENT [C]	SHOCK TO SYSTEM	CATASTROPHE	REVOLUTION	INTENTION C
boundary-conservation agent [B]	destiny	punctuated equilibrium	paradigm shift	transcendence

FIGURE 4  
THE GENERAL FRAMEWORK SHOWING THE STRUCTURE OF DEVELOPMENT IN COMPLEX ADAPTIVE, LIVING, SOCIAL & DESIGN SYSTEMS

### 2.2.4 Design as a Holistic Process

D'Aquili & Mol (1990) ask whether nature harnesses complexity in similar ways at various levels of organization. "How is wholeness reasserted in the face of the dissipation of a previous wholeness?" (ibid., 1) This question is fundamental to the social scientist, the physicist, the biologist, as well as philosophers and theologians. The idea that particles possess variable properties (such as wholeness and complementarity) which are functions of their environment is reminiscent of ideas about the balance between matter and motion put forward by Aristotle and Empedocles. D'Aquili and Mol see a continuity between the inorganic and the organic, the atom and the gene. They both absorb change (in the form of temperature or mutation) to arrive at new stable structures. Just as in chemistry, sameness is structure and change is reaction, so in biology, sameness is heredity and change is variation. In this context, selection is the outcome of the dialectic between heredity and variation (see FIGURE 4). Mendel founded the science of genetics in which the interplay between heredity and mutation was to become evident. Mutation comes about through either an imperfect copy of a gene, a recombination of genes and alleles or the acquisition of a new function by an existing structure (ibid., 31, 2). Although mutations are random, they allow the organism to adapt to a changing environment and thereby move in a specific, non-random direction. The interplay between heredity and variation allows nature to navigate somewhere between the chaos of complete change and the extinction-begetting inflexibility of no change (Jantsch's novelty and confirmation). Self-pollination and inbreeding optimize invariance compared to cross-pollination (sexual reproduction) and outbreeding. The evolutionary success of sexual reproduction lies in its equilibration between sameness and too much change (autopoiesis). It transfers plasticity on a population and facilitates the transformation of the genetic composition of that population in response to a changing environment. I hold the view that similar mechanisms (cross over, variation and selection) are part of the design process and that conscious manipulation of these mechanisms can enhance efficiency in the process and effectiveness in the product.

The equilibration between *integration* and *differentiation* is also a key feature of evolving systems. At the first control parameter level they are: *synthesis* (integration) and *analysis* (differentiation), together

responding to *information* (change agent) and developing revised *knowledge* structure (conservation agent); at the second parameter level the boundary-breaking vehicles are *primary process* (integration) and *secondary process* (differentiation), together responding to *inspiration* (the change agent) and developing *motivation* (the conservation agent); at the third level, the boundary-breaking vehicles are *intuition* (integration) and *reflection* (differentiation), together responding to *intention* and developing *operation*. These dimensions of the design process framework will be described in more detail later in this chapter.

D'Aquili and Mol quote Weiss, Waddington and Koestler to support this notion of two tendencies in an organism: self-assertive, autonomous and centrifugal as against integrative, attractive and centripetal (ibid., 36). They believe further that there is good evidence that religion, play and art represent integration and expressive representation as a counterbalance to differentiation and rational mastery. Bateson too is brought into the discussion. Cells, organs, human bodies, ecosystems, and societies are always 'conserving'. In the human mind learning conserves the opinions and components of the status quo in society. For Bateson, purpose acts against these stabilizing tendencies. Consciousness is often organized in terms of purpose which allows an individual to take short-cuts to what it wants, but pure, uncorrected consciousness leads to dehumanization (ibid., 42). In FIGURE 4 this type of consciousness appears as action based solely on intuition. Reflection provides a civilizing influence. Behaviour may be instinctive (Bateson uses the term here in my sense of *intuitive*) or learned (*reflective*) or a combination of the two. Instinctive behaviour has the advantage of swift reaction to environmental dangers or opportunities. It is however, less flexible and discriminating than learned behaviour. Behavioural sequences that contribute to personal wholeness may have a detrimental effect on social identity and vice versa. The context of an action is important in evaluating its contribution to the system. Again, the optimum is to achieve a balance between aggression and altruism.

Just as they have discussed particles, genes and instinct, d'Aquili and Mol go on to discuss symbols which they believe to be the next step on the evolutionary ladder. Structuring, classifying and ordering *information* are intrinsic functions of the brain. Priorities, connections, and relations between experiences are programmed in such a way that chances for survival are maximized (ibid, 80). In my framework, the

*analytic* and *synthetic* are the vehicles by which the mind processes information. Further, d'Aquili and Mol propose that the dialectic between expressive/emotive (the *primary* process) and instrumental/rational (the *secondary* process) symbolism is a logical extension of the wholeness/fragmentation or stability/change dialectic that I outline above. They propose this dialectic to be a better fitting model than a linear, mechanistic one for the data of both the natural and the social sciences. The authors then outline a neurophysiological basis of cognition. They describe six operators or neural structures which process sensory input by relating various elements in ways specific to that operator. These operators are similar to my modes of expression and are termed as follows (the equivalent in my terminology is shown in brackets after each): the Holistic Operator (*synthetic*), the Causal Operator (*secondary process*), the Abstractive Operator (*reflective*), the Binary Operator (*boundary-breaking vehicle*), the Formal Quantitative Operator (*analytic*) and the Value Operator (*primary process*) and present an anatomical model for each of these operators based on recent neurophysiological research (ibid., 137).

D'Aquili and Mol attempt to answer the question: why does the simple have to give way to the complex both in being and in thought? The answer which they give is "that conservation gives way to change (and often complexification if adaptation to the environment is thereby improved). Yet we have gone beyond this answer by saying that change could stand the test of time only if it could be incorporated into a new whole." (ibid., 155) The model of thinking put forward emphasizes the role of the nonrational and the emotive in an interactive and interdependent view of nature, life and society and posits wholeness and fragmentation as primary categories of being (ibid., 159).

### **2.2.5 Design as a Process of the Mind**

Two recent works which deal with the evolution of the mind and the brain are The Creative Loop: How the Brain Makes a Mind by Harth (1993) and Consciousness Explained by Daniel Dennett (1991). Dennett likens the brain to a virtual machine (made of rules rather than wires) and explains how it could have come about through the normal processes of natural selection. Unlike human designers, nature doesn't foresee side effects and as a result has developed single elements that have multiple purposes. In order to survive, organisms need to have mechanisms for sensing when a contact with the outside world is dangerous.

Dennett shows how the hard-wired human capabilities of the mind could have evolved from the basic mechanisms of anticipation, discrimination and orientation. He then shows how the emergence of phenotypes with variable or plastic wiring could speed up the gene mutation/natural selection process. This plastic brain is capable of reorganizing itself adaptively in response to particular novelties that it encounters in its environment in a process similar to natural selection. Dennett calls this postnatal design-fixing. Skinner's concept of behaviourism is one mechanism for the selection to occur but, while plausible, it is too simple for a comprehensive explanation. The Baldwin effect provides a more comprehensive explanation. If a species has considerable variation in its basic plastic wiring, and an organism is born wired with the capability for a Good Trick (a behavioural capacity that protects it or enhances its chances for survival), then others in the species with similar wiring will tend to learn the Good Trick and will pass on the wiring until it ultimately becomes genetically fixated on the Good Trick. This may look like Lamarckism (the now discredited idea that acquired characteristics can be passed on genetically) but it is not. Nothing the individual learns is transmitted to its progeny. Those that are wired for the good trick will tend to have more progeny who will also tend to be wired closer to the Good Trick. Over generations, the competition will become stiffer and unless you are born very nearly with the Good Trick you are not close enough to compete successfully (ibid., 184 - 186). Therefore evolution in the medium of phenotypic plasticity can enhance evolution in genetic variation. Strohman (1997) makes this point in relation to biology. Although the theory of genetics is clear and well accepted, it cannot alone explain the complex behaviour of organisms. Recent work in genetics is starting to uncover anomalies in the correspondence between genetic structure and the form and function of organisms. It is becoming apparent that there is not enough information in any genome to map out the details by which morphological structures arise in organisms. For example, the genome complexity found in humans and mice has no correlation to differences in form and function between them. Strohman believes that an alternative theory of evolution that emphasizes the importance of nonrandom (*epigenetic*) changes during development has great merit. "Developmental change as a source for the creation of new form equal to the 'creativity' of a random natural selection is a scientific possibility of great merit" (Strohman 1977, 195). *Epigenesis* establishes the basis for a level of organizational control above the genome: a level that is now well established but

continues to evade decisive theoretical insight. It involves the mechanisms that impart temporal and spatial order on the activity of the genes.

Another capacity that humans have is representation and Dennett believes that this is a process of generation-and-selection of patterns of neural activity in the cerebral cortex. From this capacity comes another medium of evolution: cultural evolution where there is something out there for an organism to learn that is already the product of a prior design process. "We somehow *install* an already invented and largely "debugged" *system* of habits in the partly unstructured brain" (ibid., 193). Further, Dennett proposes that the Baldwin effect could explain the human ability to autostimulate the mind (through talking aloud, writing, drawing etc.). This ability "could blaze a valuable new trail between one's internal components" allowing for new associative connections to be made (ibid., 196). This medium of evolution is characterized by *memes* or ideas (a term coined by Richard Dawkins) which Dennett speculates are 'parasites' on the vehicles of language. All evolution occurs when the following conditions exist:

- variation: a continuing abundance of different elements
- heredity or replication: the elements have the capacity to create copies or replicas of themselves
- differential "fitness": the number of copies of an element that are created in a given time varies, depending on interactions between the features of that element and features of the environment in which it persists

Under this definition, memes are the unit of replication in cultural evolution. Both Dawkins and Dennett believe that memes are literal (as opposed to analogous) units of evolutionary material. Dennett sums it up with the phrase: 'A scholar is just a library's way of making another library' (ibid., 202). Genes are invisible; they are carried by gene vehicles (organisms) in which they produce characteristic effects (phenotypic effects) by which their fates are determined. Similarly, memes are carried by meme vehicles (pictures, books, sayings, even tools and buildings) and they produce characteristic cultural effects. Cultural evolution is the fastest of the three media and is probably swamping genetic brain differences in terms of effect. Cognitive functioning is mainly a result of the structures that get built as a result of the brain's interactions with the world and Dennett quotes neurophysiologist Michael Gazzaniga in support of the view of the mind as "a bundle of semi-independent agencies" out of which "a web of discourses is

woven” (ibid., 260). I have coined the term *kenes* (after Dawkin’s term memes) for the units of replication in design. They are the basic, ordered, known facts about a context for a design and about the program requirements for a design, e.g. three washrooms will serve sixty people or south facing windows will require shading.

In a subsequent book, Darwin’s Dangerous Idea: Evolution and the Meanings of Life, Dennett (1995) shows how Darwin’s theory of natural selection is able to embrace recent theories such as punctuated equilibrium (Vrba & Gould 1986), the evolution of language and culture (Lakoff 1987), evolutionary ethics and self-organization (Kauffman 1993). For example, Kauffman proposed that the theory of self-organization could be combined with that of natural selection to give a broader foundation to evolutionary theory. Instead of a gradual accrual of organization under the steady pressures of natural selection, Kauffman postulates that selective pressure is unable to overcome an inherent tendency in populations to resolve themselves into ordered patterns. Evolution only occurs “in the regions of possible law that form the hybrid zone between stifling order and destructive chaos” (ibid., 221, 2). The conditions for evolvability have not come from the hand of a Designer but are the result of a prior evolutionary process. Evolvability is likely to evolve because it is what he calls a ‘forced move’ in the game of Design (which takes place in Design Space). Dennett says what Kauffman has discovered is not so much “laws of form as rules for designing” and quotes him: “Evolution is not just ‘chance caught on the wing.’ It is not just a tinkering of the ad hoc, of bricolage, of contraption. It is emergent order honored and honed by selection” (Kauffman 1993, 644). There are contingent moves in Design Space and forced moves. Forced moves are cases in which, for some reason, there is only one way things can be done (for example, the similar structure of the eye in vertebrates and invertebrates evolved independently). The reasons can be deep like the laws of physics or shallow like historical precedent. Contingent moves are a result of exploiting and amplifying the many contingencies of history. For Dennett, “there is only one Design Space, and everything actual in it is united with everything else” (ibid., 135). This means that human design of artifacts is united with evolutionary design. “We are not just designed, we are designers, and all our talents as designers, and our products, must emerge miraculously from the blind, mechanical processes of Darwinian mechanisms *of one sort or another* (original emphasis)” (ibid., 135,6). The differences

between natural products and artificial products come about because of the foresighted intelligence human artificers bring to a problem (leading to cumulative and negative consequences). How was Bach able to produce his music? Certainly not by running through the infinite number of alternative arrangements of musical notes. His search for beautiful music was more directed. His brain was a heuristic program for composing music, made from lucky genes, and existing in a cultural milieu of the musical memes of the times. For Dennett cranes are the heuristic devices we use to speed up our problem-solving. "Bach is precious not because he had within his brain a magic-pearl of genius-stuff, a skyhook, but because he was, or contained, an utterly idiosyncratic structure of cranes, made of cranes, made of cranes, made of cranes (ibid., 512)." Efficiencies of exploration in Design Space are the cranes (as opposed to skyhooks) that have sped up development over the ages. Bach's cranes were hierarchical and complex. I am seeking a description of the mechanisms of these efficiencies in this dissertation.

An arrangement similar to Dennett's concept of media of evolution, along with the concept of self-organization, forms the basic structure of my framework (FIGURE 4 on page 46). In describing the structure I use Holland's term of *agent* (1995) to describe the active elements in the system. There are *conservation agents* and *change agents*. The conservation agents act to maintain the structure of the system (they are the units of replication and they provide the constraints which increase the capacity of the system to override the effects of external influences). The change agents break down the structure of the system, moving it to instability and cause it either to collapse to diffuse lower levels of organization or, alternatively, to a higher level of organization with a new set of upper-level constraints. In both cases the material components of the system survive but the relationships between them disappear. If the conservation agents become dominant then the system moves to equilibrium with total confirmation and total lack of information. If the change agents become dominant then the system progresses to chaos with total novelty and total information overload. In order for development to occur, first a dynamic balance is required (autopoiesis) between what I have called *boundary-breaking vehicles* and, second a push by a change agent moves the system into chaos and the energy provided by the conserving agent forces the formation of a new dissipative structure (*reintegration*). This move requires a great input of energy and a matching production of entropy. Change in natural systems occurs at three levels: the individual, the

species and the population. Similarly, change in social systems occurs at three levels: the individual, the community and humanity. I propose that change in the system of design also occurs at three levels of control. These three different levels represent levels of scale in a nested hierarchy of part to whole.

At the first level: in complex adaptive systems (CAS) heredity is the conserving agent; in living systems it is *genes*; in social systems it is *memes* (ideas); and in design it is what I call *kenes* (units of knowledge). In CAS variation is the change agent, in living systems it is *mutation*, in social systems it is *experiment* (deviant behaviour), and in design it is *information*.

At the second level: in CAS *adaptation* is the conserving agent, in natural systems it is *resilience*, in social systems it is *tradition* (theory in science), in design it is *motivation*. The change agent in CAS is *novelty*; in living systems it is *disturbance* to an ecosystem, in social systems it is *rebellion* (anomaly in science), in design it is *inspiration*.

At the third level: in CAS *confirmation* is the conserving agent; in living systems it is *speciation*; in social systems it is *culture* (paradigm in science); in design it is *operation*. In CAS the change agent is a *shock to the system*, in living systems it is *catastrophe*, in social systems (and science) it is *revolution*, and in design it is *intention*.

The outcome (or fourth level) in CAS is *destiny*, in living systems it is *punctuated evolution*, in social systems (and science) it is a *paradigm shift*, in design it is 'transcendence' where new canonical design typologies are formulated. The entire process is heuristic and iterative and will repeat itself starting again at the first level of scale of part to whole.

Harth like Gerald Edelman (1992) attempts to construct a biologically based theory that links consciousness with neural processes. Using the phenomenon of blindsight as evidence (where patients in whom one half of the brain is inoperative and therefore are supposedly unable to see objects in the visual field of the opposite side, nonetheless can act as if they have seen an object), Harth takes the position that consciousness is something beyond the by-product of sensory information reaching the brain. He develops a model of the dynamics of thought processes that asserts that "the sensory processes that translate an

incoming picture into some central, symbolic, neural activity can be *inverted*. The thought of a sensory event, originating fortuitously or through associations somewhere in the cortex, can bring about its representation in a form that is closer to the senses. This can be accomplished through an optimization process, leading to what has been called *zoomability* [the amplifying characteristic of feedback loops]. The resulting picture-in-the-head then functions like a sensory input. This is a self-referent loop. The infinite regress of consciousness arises then in the most natural way as echoes between pairs of reflecting planes...The chaining of images is achieved by associative connections in the cortex, which trigger new concepts or ideas to be fed into the self-referent loops" (Harth 1993, 141, 2). In cognitive processing, selection of patterns is made according to a number of factors, such as the raw sense data, expectations based on previous experience, stored knowledge, and random fluctuations. Contrary to Dennett, who believes that consciousness is the product of multiple drafts of reality, Harth believes that the brain is a "theater, and the action on its stage is being scrutinized by an observer. Unlike previous attempts that have placed the theater at the highest level of cerebral activity, I believe that unification is located at the only place where sensory patterns are still whole and preserve the spatial relations of the original scene - at the bottom of the sensory pyramid, not at the top" (ibid., 144). Edelman (1992) speaks of consciousness as a remembered present where previous memories and current activities of the brain interact and Harth calls consciousness "a wedge driven between the *whence* and the *hence* [original emphasis], a timeless region where intentionality, volition, and *creativity* [author's emphasis] are spawned" (ibid., 145). Harth proposes that neural dynamics is chaotic in the same sense that nonlinear systems can exhibit chaotic behaviour. "I believe that we are dealing here with one of the most subtle of processes that exist in nature. Somehow, the top-down control that is so characteristic of living systems must exert its selective power over the myriad microscopic potentialities dredged up by the chaotic dynamics. The selection of these chance events and their elaboration through countless creative loops is the function of consciousness." (ibid., 147) For Harth the resemblance between the nonlinear self-referent properties of the Mandelbrot set and the operation of the brain which is also nonlinear and self-referent is more than a circumstantial analogy. In FIGURE 4, *information, inspiration, intention* are the top-down controls and *knowledge, motivation and operation* are the bottom-up controls.

Gregory Bateson's two books, Mind and Nature: A Necessary Unity (1979) and Steps to an Ecology of Mind (1972), outline his theory that evolution and learning must fit the same formal regularities. For Bateson, the mind (in its more complex, aesthetic, elegant and intricate aspects) is a reflection of many parts of the natural world. Human "wisdom, ...bodily grace,...and even [the] habit of making beautiful objects are just as "animal" as...cruelty. After all, the very word "animal" means "endowed with mind or spirit (animus)" (1979, 5). In order to understand the world of living things, differences and distinctions must be invoked (*differentiation*). There must be a process of trial and error and a mechanism of comparison. Since error is biologically or physically expensive, it follows that adaptive change must be hierarchic in order to effect efficiency. "There is needed not only that first-order change which suits the immediate environmental (or physiological) demand but also second-order changes which will reduce the amount of trial and error needed to achieve the first-order change. And so on. By superposing and interconnecting many feedback loops, we (and all other biological systems) not only solve particular problems but also form habits which we apply to the solution of classes of problems" (1972, 274). Bateson is seeking to uncover the laws of what he calls *the pattern which connects*. For Bateson the perception of aesthetics is the response to this pattern which connects. The similarities in the anatomies of animals exhibit three levels (or logical types) of descriptive propositions. First, there are first order connections (the parts within an animal compared to other parts within the same animal). Second, there are second order connections (the parts of one animal compared to the parts of other animals). Lastly, there are third order connections (the comparison of parts of one animal to the parts of another animal compared to another comparison of parts of one animal to another). The pattern which connects is a pattern of patterns (or a metapattern) (1979, 11). Context is pattern through time. Without context, words and actions have no meaning. Growth and differentiation must be controlled by communication. Bateson believes that thought and learning resemble evolution since they are stochastic processes (a stochastic process is one in which a sequence of events combines a random component with a selective process so that only certain outcomes of the random are allowed to endure). When two or more information sources come together they can give information of a sort that is different than either of the two original sources. The evolutionary process depends upon such double increments of information. Every evolutionary step is an

addition of information to an existing system and can determine the direction of change for that system (ibid., 8 - 21). In internal change for a system (which could be a man, A and a dog, B), interaction makes information about the parts of the system available (B bites when A touches) and the learning process that comes from that interaction results in a change of boundaries between the subsystems. There is no new information from outside the system only new information between the subsystems (A has learned not touch B). Bateson calls this *new patterns of interaction* and the interaction between A and B has resulted in the natural selection of a new pattern of interaction (ibid., 138). Bateson makes it clear that, while we tend to view evolution as a clever and ingenious process which leads inevitably to 'fit' products, when viewed hierarchically it is not at all clear that changes that benefit at one level of logical typing (the individual) will necessarily benefit the next level of logical typing (the society). Nonetheless, I maintain that in design, the logical type of the individual designer must be subsumed by the logical type of the design team in order for design to be more holistic. Bateson lists a series of potential negative outcomes from innovation including: positive feedback loops (where an effect is intensified by its feedback); destruction of an ecological niche; inappropriate assumptions of independence; and addiction (ibid., 173,4). The rate of change is however limited by three factors: first, the barriers between somatic and genetic change; second, sexual reproduction which retains much of the old DNA blueprint; and third, epigenesis which is a convergent and conservative system. Bateson also points out that natural selection acts at the level of the internal stress of the organism as well as the level the environmental circumstances to which the organism is subjected. Further, in the second stochastic system (the mind), the interaction between the phenotype (characteristics) and the environment provides the random component to the system. If creative thought is fundamentally stochastic "we are looking for a binary division of thought process that will be stochastic in both of its halves, but the halves will differ in that the random component of one half will be digital and the random component of the other will be analogic" (ibid., 183). Bateson uses analogic and digital in the same sense as I use integration and differentiation. He pinpoints epigenesis as the natural process that resembles the selective element of the mind. He also pinpoints adaptation as the natural process that resembles the selective element of the relationship between the brain and the world around it. He proposes that these two components are "rigour and imagination, the two great contraries of mental

process, either of which by itself is lethal” (ibid., 219). Bateson’s rigour and imagination are the equivalent of the conservation and change agents in my framework. The two must be in balance for healthy minds and ecosystems. “Obsolescence is not to be avoided by simply speeding up change in structure, nor can it be avoided by simply slowing down functional changes. It is clear that neither an over-all conservatism nor an over-all eagerness for change is appropriate” (ibid., 225).

Bateson develops a set of criteria for minds (which are shared by ecosystems):

- a mind is an aggregate of interacting parts or components
- the interaction between parts of mind is triggered by difference
- mental process requires collateral energy
- mental process requires circular (or more complex) chains of determination
- in mental process, the effects of difference are to be regarded as transforms (i.e. coded versions) of events which preceded them
- the description and classification of these processes of transformation disclose a hierarchy of logical types immanent in the phenomena

### ***2.2.6 Design as a Process of the Brain***

Edelman (1992) has developed the theory of neuronal group selection, as well as the concepts of reentry and global mapping. These form a basis for his claim that biology can explain consciousness. He believes that consciousness arose as a phenotypic property during evolution and makes a distinction between primary consciousness (which is having mental images of the present) and higher-order consciousness that involves having a model of the self, the past and the future as well as the present. Along with Lakoff (1987), Edelman shows how thought depends critically on the body and the brain and concludes that the mind is not transcendental nor is it a machine. Rather it is a special kind of process depending on special arrangements of matter. Although Edelman does not discuss design, his hypothesis that consciousness can

be explained solely by evolution is critical to my position. Design is a process involving higher-order consciousness and as such must then be explainable in terms of evolutionary processes.

Ben Goertzel (1993) extends these ideas further in a book called The Evolving Mind in which he lays out a hypothesis that mental process is itself a form of evolution. "When you think, remember or feel, the process going on in your head is actually a process of evolution by natural selection" (ibid., xiii). A number of authors have explored this topic (Goertzel cites Bateson, Holland, Edelman and others) but Goertzel believes that strict Darwinism must be supplemented by an evolutionary theory which embraces the self-organizing properties of complex systems. The two dynamic systems which are common to ecosystems and mind/brains are: evolution by natural selection and form creation by sexual reproduction. Like Bateson, Goertzel defines the 'stuff' of the natural world as *pattern* and defines the concept of *emergent pattern* as that which emerges between two entities if it is present in the combination of two entities, but not in either of the entities separately. *The structural complexity* of an entity is defined as the total amount of pattern in it. He shows how, in immune systems, survival is roughly proportional to emergence (those antibodies which generate a large amount of emergent pattern, in conjunction with other antibodies, will tend to survive) and suggests that this correlation also applies to the evolution of species. An ecosystem is thus a "system of pattern equations". He then goes on to suggest that complex structures evolve by a process called *systematic structural instability*. Structural instability occurs when a small change in the input to a process leads to a large change in the structure of the output. "A hierarchical process possesses systematic structural instability if: 1) each of its levels takes as input *patterns* in the levels below it, and 2) each of its levels contains some structurally unstable processes (ibid., xvii)." In design, new patterns are formed when a change agent is acted on by the boundary-breaking vehicles and a reintegration to the next level occurs. The new patterns are evident in the level above. Like Edelman, Goertzel models the brain as a network of neuronal groups. Maps are connected sets of neuronal groups which tend to act as a unit. Brain dynamics lies in the structure and dynamics of the network of interconnected maps. Goertzel proposes first, that neural maps are structured hierarchically and interact according to the multilevel methodology and second, that there tends to be a large amount of emergent pattern generated between nearby maps. Using the theory of genetic optimization Goertzel proposes

thirdly that neural maps reproduce sexually and differentially. Together these three proposals “imply that: the neural maps in any given brain may be modeled as a population reproducing sexually and evolving by natural selection (and creating new form by systematic structural instability)” (ibid., xvii). Since there is no biological evidence to support these proposals, Goertzel looks to psychology and introduces his own dual network model of mind from which one can deduce the three proposals. Finally, Goertzel shows that as the size of a dual network increases, its effectiveness may experience a sudden jump or “*phase transition*” and notes that this implies that the evolution of intelligence was perhaps a case of punctuated equilibrium.

Goertzel points out that the thermodynamics based approach to evolution adopted by Jantsch and Prigogine does not provide a language in which to speak of a pattern based approach. A pattern is *a representation as something simpler*. Patterns reduce self-organization to certain relations between entities: “everything is made of relationship” (ibid., 2). Since pattern is not an objective quality, Goertzel looks to universal computation to provide an ‘objective’ definition of complexity (as an aspect of pattern) and uses the Kolmogorov-Chaitin-Solomonoff (KCS) definition. “[T]he complexity of x is the length of the shortest self-delimiting program for computing x, where a self-delimiting program is one which contains, at the beginning, a message for saying how long it is (ibid., 6).” KCS as a measure of complexity is supplemented by the idea of logical depth. Logical depth is the running time of the shortest program which computes it. Fractals are examples of complex systems which have low KCS complexity but high depth complexity. However Goertzel feels that neither definition is comprehensive and offers a third definition: complexity is structural complexity or a measure of the total amount of pattern in an entity. Natural selection works by random mutation of the genetic material of organisms, i.e. of the programs for computing programs. Goertzel suggests that these programs are guided by the principle of minimizing KCS complexity while maximizing structural complexity (ibid., 280). The goal of natural systems was first put forward by Darwin and Wallace and it is *survival*. The goals of artificial systems must be defined artificially. Strict Darwinism emphasizes gradual adaptive change produced by natural selection acting exclusively on organisms resulting in a set of traits. The self-organizational theory of evolution emphasizes that it is “impossible to decompose an organism into a vector of traits: that the qualities which

characterize an organism are deeply interconnected, so that small changes induced by random genetic variation will often display themselves throughout the whole organism...the environment of an evolving organism consists partly of other evolving organisms, so that the organisms in an ecosystem may be "optimal" only in the weak sense of "fitting in relatively well with one another" (ibid., 46)." The difference between the two theories is in the estimates of the relative frequencies of situations in which different phenomena are important.

In sexual reproduction it is difficult to see which is the relevant unit of selection: the gene; the individual; the species or a higher level. One approach to resolution of this difficulty is Gould's division of levels in a hierarchy. For each level, the set of all properties of entities on that level is partitioned into two disjoint sets: emergent and aggregate. Emergent properties arise from the organization of lower level components. Aggregate properties are deducible from the inherent properties of lower level components. Selection on any level is defined as the "interactions between heritable, emergent character variation and the environment that causes differences in rates of birth or death among varying individuals" (Vrba and Gould 1986, 219 quoted in Goertzel, 58). I have called the emergent properties *integrative* and the aggregate properties *differentiative*.

Goertzel also notes an example of *directed evolution* where bacteria developed mutations required to survive in the sugar salicin at rates far in excess of the expected rate in normal circumstances. He speculates that this may be a result of systematic variance of mutation rate. This is reminiscent of Dr. Johnson's quote that "when a man knows he is to be hanged in a fortnight it concentrates the mind wonderfully". Goertzel supports Edelman's theory that connections between the cells in the brain are formed by a self-organizing process by which the connections attempt to iteratively settle into a consistent and useful pattern (ibid., 64). Extending this notion to all organisms, Lima de Faria claims that there are universal self-organizing processes which are responsible for fundamentally new occurrences. Goertzel contends that this is not incompatible with Darwin's theory of natural selection. As Gould has argued "natural selection adjusts the parameters which other forms of dynamics identify as free for adjustment" (ibid., 69).

Goertzel examines self-organization in the light of Odum's work on ecosystems and Prigogine's work on chemical, thermodynamic systems. Odum's (1994) approach depends on physical concepts of energy flow but can never deal with the qualities of an ecosystem which might emerge. Goertzel's structural view on the other hand focuses on patterns of matter and energy distribution (ibid., 90). Prigogine & Stengers (1984) have developed nonlinear models of chemical and biological structures which are based on microscopic physical dynamics. They believe that chaos is the most important kind of dynamics for the study of complex systems but Goertzel believes that they are not necessarily the most important, only the most easily studied using nonlinear differential equations and difference equations.

Goertzel proposes that brains, minds, ecosystems and societies have future structures that are tractably determinable from their past structure even though their future state is not tractably determinable from their past state. He goes on to look at the brain and the mind in more detail. "The brain appears as a network of neural networks, which self-organizes itself according to the logic of evolution by natural selection and creates new ideas by a multilevel process that incorporates a form of abstract "sexual reproduction" (ibid, 99). Edelman's (1992) theory of Neural Darwinism, where the processes of mutation and selection are postulated to generate complex structures such as those found in the mind, seems insufficient to Goertzel. Goertzel proposes that neural maps reproduce by *crossover* as well as mutation (Holland's later work in genetic algorithms also takes this approach). His theory proposes eight crucial mental processes and gives their interconnections: the Perceptual Hierarchy; the Motor Hierarchy; the Optimizer; the Adaptor; Induction; Deduction; Analogy; and Structurally Associative Memory.

Goertzel accepts Bateson's six criteria for minds but finds them necessary but not sufficient. For Goertzel, the necessary and sufficient condition is the presence of an efficiently functioning dual network, incorporating evolution by natural selection, creativity by crossover and complex subsystems of interlocking, inter-generating patterns. Finally, Goertzel accepts Brown's theory that microgeny (the development of individual thoughts) recapitulates phylogeny (the historical development of thought) and extends it to propose that the phenomenon of 'sudden insight' can be likened to Prigogine and Stengers

idea of a phase transition. "A sudden insight...is actually a recapitulation of the historical evolution of intelligence" (ibid., 181). This is a description of the 'click' that I describe in Chapter 1.

In order to describe the phenomena of the world, including minds and brains, Roth & Schwegler (1990) put forward a middle ground between the extremes of reductionist science and what they term holistic emergentism. They call their position non-reductionist physicalism. This is the position that I adopt in developing the framework for the design process. The fact that at different levels of complexity systems show properties that are not reducible to the properties of their components means that emergent properties exist. However, they believe that properties and modes of interaction define each other mutually and that whenever certain entities become components of a new system they will show new modes of interaction and as a result, new properties. It is the language of physics that must be used to describe basic natural and mental processes and while that language may not be useful to describe higher levels of complexity, all the concepts and terms used in other complexity-dependent languages must be translatable into physical terms. Truly biological laws, for example, evolutionary laws, can be expressed in physical terms without being reducible to physical laws. "The properties of the objects and processes are constituted by interaction, which allows any kind of smooth or dramatic change of properties, and...there is no "true" nature of objects beyond these interactions" (ibid., 49).

### ***2.2.7 Design as a Self-Organizing System***

Kuppers (1990) states that the natural sciences are undergoing a fundamental paradigm shift and indicates that the humanities are also indicating signs of being affected by it. He defines paradigm shift in Kuhnian terms. The highest states of order known to us are living systems and their complexity-generating, irreversible natural processes are denoted by the general term "self-organization". Kuppers calls this shift a transition from a "physics of being" to a "physics of becoming" (ibid., 53). He asserts that the complexity of natural phenomena lies in the complexity of their boundary conditions and not in the complexity of the natural laws to which the phenomena are subject. Physical theories possess both general statements in the form of laws with at least a local validity, and initial or boundary conditions which are not fixed by the theory but are specified in the area of applicability of the theory. The initial conditions are the selection

conditions of solutions to the differential equations that describe the physical laws. In simple physical systems the boundary conditions (e.g. the position and momentum of a body at a particular moment) are contingent qualities. They are marginal quantities and restricted only by the range of validity of the natural laws in question. However, the boundary conditions of complex systems are not contingent quantities since any significant change would also change the dynamics of the system. "The dynamics of a complex system depend very sensitively on its boundary conditions" (ibid., 56,7) If the paradigm of self-organization is capable of forming a unified theory (which Koppers calls a theory of boundary conditions) then this theory would occupy a middle position between the natural sciences and the humanities and "will be the means of the mutual approach of these two branches of thinking" (ibid., 61). This idea of the sensitive dependency of a system on its boundary conditions is brought up again by Krohn & Koppers (1990). "The analysis of the dynamics of recursive processes has led to a theorem of great consequence: already in the case of deterministic systems, the sensitive dependency on boundary conditions can lead to great structural changes at the slightest perturbation. But, equally important, a high degree of perturbations can also be neutralized. From this follows that the actual behaviour can only be predicted by theory slightly" (ibid., 209). This observation is crucial in relation to the application of the theory to mental processes. In the new systems view of self-organization "the system itself defines and differentiates its own boundaries, thereby constituting everything as "environment" that is beyond this boundary. The relation between system and the environment is organized by a set of boundary conditions that constrain the arbitrariness of the structures of the system and expose it to evolutionary selection" (Nowotny 1990, 229). A system has its own distinctions as to what constitutes information about the environment and information is not transferred from the environment to the system since for in order to constitute information a distinction has to be made that allows the separation of 'this' from 'that'. A boundary must be drawn so that self-observation becomes possible. Each concrete subsystem of society is based upon a binary code which allows the distinction between 'possible' and 'not possible'. This binary code performs a number of functions: integration of the two opposites; production of paradox; and further differentiation of the system along the lines indicated by the binary code. I have grouped these functions together under the term *boundary-breaking vehicles*. Subsystems can export distinctions that can then become relevant

information for other subsystems. The binary code of science is the true/false dichotomy. This making of distinctions is essentially a creative act. I have called this process *differentiation*.

Roger Lewin asks if innovation is basically the same process in all complex adaptive systems: "How consistent a pattern is there in innovation in complex adaptive systems such as these? Each is affected by historical contingency, but to different degrees. It is surely significant that, with all these differences of detail - in the biological, cultural, and technological realms - the overall pattern is remarkably similar. It encourages the belief that consistency of pattern is more than mere coincidence" (Lewin 1992), 71).

### **2.2.8 Design as a Complex Adaptive System**

John Holland (1995) looks to the development of the lever points of complex adaptive systems (CAS) as a way to investigate their properties and develop a theory about them. CAS are composed of interacting agents described in terms of rules. Holland describes four properties and three mechanisms of CAS which he believes are basic. These are aggregation, nonlinearity, flows, diversity, tagging, internal models and building blocks. Simplifying the reproductive process considerably to consider only the reproduction and recombination of chromosomes, Holland proposes two genetic operations: *crossing over* (which causes the characteristics of the parents to appear in new combinations in the offspring); and *point mutation* (which is the process whereby individual alleles are randomly modified, yielding a different allele for the gene). The second operation is much rarer than the first. Holland uses these concepts to develop computer simulations of complex adaptive systems. In my description of the structure of complex adaptive systems I have called the crossing over operation *boundary breaking vehicles* and point mutation a *change agent*.

### **2.2.9 Design as a Creative Process**

If adaptation is the process by which an organism is 'fitted' to its environment, then creativity provides a mechanism for humans to develop in ways that 'fit' their environment. In common with many writers on creativity, I define creative products as those which are novel and have value. I extend this definition to add that creative products are emergent. Emergent qualities are those which are present at a higher level in a system but not at a lower level and result from the interaction of the lower level components. (I am

indebted to Dr. Lavkulich for this insight). When humans design novel and useful products that help them to adapt to their environment, then they are being creative. Creativity involves boundary breaking.

Koestler (1964) proposes a theory of creation which is a description of the conscious and unconscious processes underlying scientific discovery, artistic originality and comic inspiration.

Koestler states that in the history of ideas there are two opposite processes at work: the downward approach from the complex to the elementary and the upward approach from part to whole. Emphasis alternates between them until they meet and merge into a new synthesis. This notion of merging of opposites is central to Koestler's theory. He uses the Roman god Janus (who guarded the gate to the city of Rome and had a head that faced both forward and backward) as symbolic of the essence of his theory. The basic idea is that the pattern of the creative process is the discovery of hidden similarities and that all patterns of creative activity are trivalent; that is, they can be in the service of humour, discovery or art and are correspondingly emotionally aggressive, neutral or sympathetic. He suggests that creative acts are the result of being able to perceive a unified situation or idea in two self-consistent but normally incompatible frames of reference. He terms this capability bisociation and suggests that it causes an abrupt transfer of a train of thought from one 'matrix' (schemata or mental set) to another governed by a different logic or rule of the game. This is the mechanism by which habits can be broken. "Habits are the indispensable core of stability and ordered behaviour; they also have a tendency to become mechanized and to reduce man [sic] to the status of a conditioned automaton. The creative act, by connecting previously unrelated dimensions of experience, enable people to attain a higher level of mental evolution. It is an act of liberation - the defeat of habit by originality." (Koestler 1964) In invention or scientific discovery the coming together of two previously unrelated concepts results in the (neutral) emotional release of surprise: "*aha*". In humour the coming together of two previously unrelated ideas results in the (aggressive) emotional release of laughter: "*haha*". Finally, in aesthetic appreciation or in the pursuit of an art, the (empathetic) emotional release at the coming together or the appreciating of the coming together of two previously unrelated themes or subjects results in the feeling of a fusion of the self with other: "*ahh*". These distinctions

between different kinds of creativity relate to the change agents at the three levels of the design process framework: information; inspiration; and intention.

Koestler ends his book by listing the main distinguishing features of associative and bisociative thought. These opposing features of habit and originality are all aspects of the framework which I have developed and they are shown in FIGURE 5.

Habit	Originality
<ul style="list-style-type: none"> <li>• Association within the confines of a given matrix</li> <li>• Guidance by pre-conscious or extra-conscious processes</li> <li>• Dynamic equilibrium</li> <li>• Rigid to flexible variations on a theme</li> <li>• Repetitiveness</li> <li>• Conservative</li> </ul>	<ul style="list-style-type: none"> <li>• Bisociation of independent matrices</li> <li>• Guidance by sub-conscious processes normally under restraint</li> <li>• Activation of regenerative potentials</li> <li>• Super-flexibility (reculer pour mieux sauter)</li> <li>• Novelty</li> <li>• Destructive-Constructive</li> </ul>

FIGURE 5 KOESTLER'S DISTINGUISHING FEATURES OF HABIT AND ORIGINALITY (1964, 666)

Other authors have noted and explored this idea of fusion in creativity. Arieti (1976) argues that creativity is a combination of primary and secondary process mechanisms. Rothenberg (1979) proposes that creativity results from Janusian and homospatial thinking which involve the overlapping of two unrelated ideas to form a new whole.

Grossman (1994) makes a direct analogy between the creative act and the theory of evolution. He takes the position that the central feature of evolution (randomness processed through a selection system yields purpose) is also the central feature of creativity. Transcendent thinking (the sudden, discontinuous pattern shifts that lead to new insights) can be explained by continuous processing. The discontinuity is treated as a behavioural or affective phenomenon. Novel solutions come about as a result of an incremental moving away from the beginning conception, set in motion by feedback concerning the inadequacy of a proposed

solution and incorporation of this new information into new solution types. The creations of Watson and Crick (the double helix), Edison (the kinescope), Picasso (Guernica), Kekule (the structure of benzene), Coleridge ("Kubla Kahn") and Darwin (the theory of evolution) are cited as instances illustrative of this long drawn out process of development. Grossman discounts the 'sudden flash of insight' as contributing to these creations. This position ignores the subjective experience of the moment of transcendence or, as I call it, the 'click'. Undoubtedly the process of creating is an incremental one but it is punctuated by moments when there is a subjective experience of a coming together of previously unrelated ideas. In Complexity Roger Lewin quotes Tom Ray, the biologist who developed the evolutionary computer program Tierra "I remember clearly when I conceived the idea of evolution in a computer...It all came in a rush of ideas, complete, everything I wanted to do" (Lewin 1992, 87).

Grossman also points out that recent research on how the brain works shows that randomization is at cross-purposes to ordinary mental function. The mind appears to be a self-organizing pattern-making system and the process of cultivating non-patterned stimuli is difficult. Habits, including habits of thought, are hard to break. I would argue that the breaking of a habit requires a process similar to that of design as outlined in the structure of development in complex adaptive systems in FIGURE 4. Change agents are needed at all three levels. For example to stop smoking, information (that smoking kills) is a necessary but not sufficient condition. Inspiration (I am harming my unborn child) is also necessary but again is not sufficient. Intention (I have made up my mind to do it) is the final condition. It is unlikely that the third condition will be met without the groundwork which comes from the other two levels.

Arieti (1976) believes we can recognize developmental processes similar to evolution in human creativity. "[B]oth biological evolution and civilization may follow norms applicable to various systems, as general system theory teaches" (ibid., 401). He gives several examples of biological creativity in the central nervous system and states that "mutations provide the raw material of evolution: blind variations. Special environmental situations act like secondary-process mechanisms and transform pathological forms into something new, more complicated, and capable of survival" (ibid., 403). Biological evolution has in its favour the benefit of extended time as well as the survival and genetic reproduction of favourable

combinations. On the other hand, humanity has cumulative experience transmitted from previous generations and conscious purpose and goal-directedness. With these, humans can reduce the time required for creativity. "Man's primary process has replaced nature's blind variations, and the secondary process has replaced the proper environment" (ibid., 404). Arieti proposes a tertiary process which allows us to see or generate a new unity from the emotional perception of the primary process combined with the rational perception of the secondary process. Arieti also uses a systems framework for his discussion of creativity. He points out that creativity is an open system where the initial conditions do not determine the final outcome.

## **2.3 Project Design as a Complex Adaptive System**

### **2.3.1 Introduction**

Those who study complex adaptive systems are beginning to find some general principles that underlie all such systems.

Murray Gell-Mann

Project delivery and design exist to bring into being a 'project'. Every project is unique because of its different requirements and context. Therefore, the course of the development of a project is unique in certain particulars and standard in others. Each project can be described as having emergent qualities and requiring the development of new patterns of the components. Every project therefore requires creativity in both its project design process and its design product.

I propose that since the human mind is a complex adaptive system, one can expect that it will follow the same kinds of processes as other complex adaptive systems. Both natural systems and mental systems use processes that lead to the creation and reproduction of designed things (Dennett 1995). Natural systems produce "designs" that "fit" their environment, therefore mental systems that more closely follow the processes of natural systems should produce "designs" that "fit" their environment. The environment for human design products is the economic, social and ecological context.

Hooker proposes modeling science as "a component or aspect of the overall dynamics of evolution/development characterizing life on this planet" (1995, 35). He states

“There is nothing in the diverse evidence for the gradual development of increasing physiological and neurological complexity to suggest anything but a single natural process. The correlative development of behavioural complexity, including social organization and communication, shows a similar continuity...Living systems are dissipative, far-from-equilibrium structures stabilized by an energy flow and open to environmental interaction. Adaptive self-organizing processes in these systems incorporate order (negative entropy) available from the environment to produce function-supporting molecular structures which express it as increasing systemic regulatory structure.” (Hooker 1995, 49)

Gell-Mann states that the common feature of all CAS “is that in each one a complex adaptive system acquires information about its environment and its own interaction with that environment, identifying regularities in that information, condensing those regularities into a kind of ‘schema’ or model, and acting in the real world on the basis of that schema. In each case, there are various competing schemata, and the results of the action in the real world feed back to influence the competition among the schemata.” (Murray Gell-Mann 1994, 17)

I will model design process as a complex adaptive system. Project design is seen as a second layer in the project delivery process and since it involves multiple players is not explicitly modeled but it is seen as a non-linear elaboration of individual design process.

### ***2.3.2 Project Design as a Creative Process***

The anxiety of creativity is unbearable. I only hope it lasts forever.      Oscar Wilde

Project design involves problem solving on many levels. A building project can be seen as a gap between an existing state and a desired state. The project delivery team members bring their experience and skills to bear on the problem of diminishing this gap. Problem solving is “the generation and selection of discretionary actions to bring about a goal state...creative thought represents a form of problem solving” (Mumford, Reiter-Plamon, et al. in Runco 1994, 3). Creativity research has sought to unravel the cognitive

processes that contribute to the production of novel problem solutions (ibid., 5). My definition of creativity goes beyond the consideration of only cognitive processes to include both the affective (emotional) and the volitional (the striving or conative). Together these three processes are thought to describe the totality of the human mind (Torrance & Rockenstein 1988). Cognitive processes deal with *information*, affective processes deal with *inspiration* and volitional processes deal with *intention*.

Arthur Koestler, in The Act of Creation, developed the theory that creativity is merely the highest manifestation of a phenomenon which is discernible at each successive level of the evolutionary hierarchy. It is "an actualization of surplus potentials" (Foreword by Sir Cyril Burt, in Koestler 1964). In addition to Koestler, there are other authors in creativity and aesthetic appreciation whose work is particularly relevant to my propositions. Berlyne (1971) has carried out work in experimental aesthetics. Amabile & Stubbs (1982) have researched the measurement and promotion of creativity amongst schoolchildren. Rothenberg (1979), a psychiatrist, developed a theory of creativity based on oppositions called Janusian and homospatial thinking. Rose (1992), also a psychiatrist, developed a theory of aesthetic appreciation based on the balance of primary and secondary processes. Lastly, de Bono (1985) and Adams (1986) are practitioners and action researchers in techniques that enhance creative potential.

If project design is seen as a process which moves an existing situation to a desired state, then the participants in that process must make projections which are then tested to see if they move the situation closer to the desired state. Hypotheses are continually tested for 'fit' to end state. Most projections will be based on previous results in similar situations but, since each project is unique, particular circumstances will need to be addressed slightly differently. Creativity is required to some degree on almost every project. For the project team to be able to maximize their combination of skills, experience and capacity for creativity it is essential that they all understand clearly the desired end state. Only in this way can they take the risk involved in proposing creative ways to reach the desired end state while attending to the particular context which the desired end state will inhabit.

## **2.3.3 Design Process Models**

### **2.3.3.1 Models**

When we meane to build, We first survey the Plot, then draw the Modell.     Shakespeare

Modern science constructs models of natural processes and uses them to reason from known cause-effect relations to unknown causes of known effects. Design constructs models of what could be. Models simplify complex phenomena and disclose order (Mitcham 1995).

Judson describes three classes of models: those that model the performance of objects; those that model the behaviour of elaborate systems; and those that contribute to theory-making. I propose a model of the second type. This type begins as a map and complex data, whose interactions are not fully understood, are selected and related to each other. Changes in certain parameters are introduced into the system and their interactions are followed. The purpose of the model is to predict outcomes (Judson 1987).

Holland points out a major value of models: “we can anticipate consequences without becoming involved in time-consuming, possibly dangerous, overt actions” (Holland 1998, 10). He goes on to suggest that models have a key role to play in the study of emergence since they make “anticipation and prediction possible” (ibid., 11). Further, he says “Here we come to a central point about model building, innovation, and the study of emergence: building a model, or developing a theoretical construct in science, is *not* [original emphasis] a matter of deduction. The standard deductive presentation of theoretical constructs in science hides the earlier, metaphor-driven models that lead to the constructs” (ibid., 9)

### **2.3.3.2 Design: The Relationship Between Process and Product**

Design is a subset activity within the project delivery process. Practically everyone involved in a project carries out design in some sense. The project manager designs a project delivery process. The electrical engineer designs an electrical system. Even the contractor has to design his construction methods.

Herbert Simon in Sciences of the Artificial (1979) states “Everyone designs who devises a course of action aimed at changing existing situations into preferred ones”. Pye in The Nature of Design (1964) says that design is “the business of ensuring that at least you get the change you want along with all the others which

you don't such as heat, noise, wear, and the rest". Buchanan & Margolin (1995) call design "the place where theory and practice meet for productive purposes". Dennett (1995) calls design "an exploitation of Order for a purpose". Alexander (1964) defines design as "the process of inventing physical things which display new physical order, organization, form, in response to function". Finally, Jantsch (1975) states that design "appears as the core of purposeful and creative action, of the active building of relations between man and his world".

Design distinguished as a separate activity from the making of things is a relatively recent phenomenon. The word design is used to refer to activities ranging from the highly constrained and well-defined problems of engineering to the unconstrained and ill-defined problems of fashion and textiles. Architectural design, which Schon (1985) has called the "the very prototype of design activity" is generally considered to apply to the class of problems called 'wicked' by Horst Rittel. This class of problems defies complete description and lacks the clarity of formulation found in scientific problems. The information needed to understand these problems depends upon ideas for solving them and there is no one 'correct' or even optimal answer (Lawson 1994)..

The early models of design process varied but in general agreed on a basic flow of: problem statement; analysis of the problem; synthesis of a solution; evaluation of the solution and communication of the solution (6). This process was described as linear with a recycling loop back to synthesis if the evaluation was negative (Mackinder & Marvin 1982). Lawson questions this basic model and denies that the process in reality is as neatly categorized. He suggests that designers come to understand their problems through their attempts to solve them; i.e., "analysis through synthesis". He also raises the question of how the designer controls the necessary shifts of mental gears (Lawson 1994).

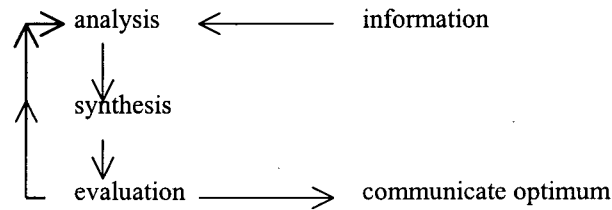


FIGURE 6 THE TRADITIONAL MODEL

Prior to design becoming a distinct activity from the making of objects, the act of design was inextricably linked to the making of the object through a slow 'evolutionary' process of trial and error. George Sturt was a traditional craftsman who set out the craft processes he followed when making wagons in a book called The Wheelwright's Shop. He shows how the two striking qualities of well-crafted products (exact matching to requirements and interaction of the parts) arise from: first, the long period of trial and error in the development of the form and second, the absence of fashion (when symbolism of feelings not directly associated with the wagon are introduced). Both these qualities are measures of 'fitness' to context: the first arising from long periods of testing small innovations and rejecting those that are less effective; and the second arising from observing the effect of those changes on other parts and adjusting the parts to suit the new conditions.

Because the trial and error process is too slow for the pace of our modern world, the design process has been separated from the making process. For example in industrial design, a designer makes drawings or models from which prototypes are made and tested until the final design is ready for production. The benefits of this separation are increases in rates of production and the ability to make much larger and more complex objects. The loss has been in the area of the two qualities of craft: the exact matching of requirements and the interaction of the parts. Along with the technological advances and the increased production, have come the unintended consequences and failures of modern architecture (Mitchell 1993).

A critical elaboration of this view entails the design of buildings so that they are able to adapt to changing requirements. In How Buildings Learn (1994), Brand states that the 'craft' approach to the design of buildings should apply to the more stable components such as the site response, the structure and the skin. These are what I have called *kenes*. I would add that design responses to the more stable 'patterns' of

human life should be treated as durable components. Christopher Alexander says: "we must first learn to discover patterns which are deep, and capable of generating life. We may then gradually improve these patterns which we share, by testing them against experience" (Alexander 1979).

Dias and Blockley argue that the structure of the design process should correspond to the structure of the product, since there is a flow of causality from process to product. Such correspondence should make the process more efficient and synergistic (Dias & Blockley 1994).

In design process the term *move* is akin to its meaning in chess. It is a step, an act, an operation which transforms the design situation from its previous state (Goldschmidt 1995). It is dynamic and involves making choices.

As shown above, there are certain elements of the design product that should be stable and relatively unchanging. The factors that lead to these elements are geographic, technical or socio-economic and they relate to the cognitive function of conserving agents. They become a driver of *forced design moves* along with other drivers such as gravity and the physical properties of materials. Forced design moves are those that the designer regards as inevitable or unchangeable.

Other elements of the design product need to be fluid to respond to changing requirements. For Brand, the building services, space plan and interior fittings are subject to accelerated rates of change. Additionally, certain aspects of the program and behaviour of users are subject to change. These elements relate to the cognitive function of change agents and become a driver of *contingent design moves*. Contingent design moves are those that the designer regards as temporary or changeable.

Through a combination of forced and contingent design moves, the designer progressively evolves the form of the building.

### **2.3.3.3 Design Process Models**

Existing models of the design process have a common thrust: there is a set of processed givens which generate design-moves. The underlying assumption is one of simple cause and effect. One model which

presents a potentially richer and more elaborate view of design has been proposed by Gabriella Goldschmidt (1983).

She believes that design requires a double layered model for explanation. As mentioned previously, design today is more complex than in the past. Goldschmidt's model takes into account this complexity and the increased emphasis on contingent design-moves that it reflects. Her model is useful because it attempts to demonstrate the connections between the internal and external constraints of a design and points a way to improving 'fitness' of the product (1983, 7). This 'funnelling' of the design possibilities as the design evolves is nicely stated by Frank Lloyd Wright who is quoted by Kauffman in a discussion of design process:

"There is the fluid, elastic period of becoming, as in the plan, when possibilities are infinite. New effects may then originate from the idea or principle that conceives. Once form is achieved, however, that possibility is dead so far as is positive creative flux" (Kaufmann 1955).

Goldschmidt has proposed that the design process has four components termed:

[A] -the set of design imperatives (the functional needs, cultural heritage, climate and site characteristics, and available resources) which are givens, relevant to the design task; e.g., the program and a site inventory and impact assessment;

[B] -the imperatives ([A] above) prioritized, interpreted, personalized; e.g., ideas, exploratory sketches and rough models of alternatives;

[ $\alpha$ ] -additive to [A], is the independent contribution of the designer which acts as a catalyst in the transformation of [A] to [B]; e.g., the celebration of light in buildings which may come from the designer's inner life and personality;

[AD] -the product: the design of a specific physical form; e.g., schematic design drawings, models. It is difficult to draw a line between the end of [B] interpretation and the beginning of [AD] the architectural design.

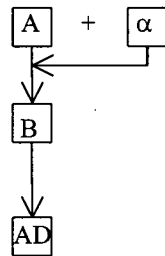


FIGURE 7 GOLDSCHMIDT'S MODEL OF THE DESIGN PROCESS

#### 2.3.3.4 The Proposed Design Process Model

While Goldschmidt's model is an improvement over the simple analysis/synthesis/evaluation model, it still is inadequate for explaining the dynamics of the design process. It does not take explanation much beyond the traditional model's 'black box' embedded in a linear but looping process.

The elaborated model I present is in the form of a framework intended to disclose the dynamics that exist in design process and to show that a relatively simple set of processes can result in complex products.

I outline these in *FIGURE 8* using the framework shown in *FIGURE 2*. I elaborate Goldschmidt's schema to explain the nature of the alpha [ $\alpha$ ] as integrative: a combination of synthetical, primary and intuitive processes and I add beta [ $\beta$ ] as differentiative: a combination of analytical, secondary, and reflective processes. The [ $\alpha$ ] are integrative design moves which aid in the interpretation of Goldschmidt's [A]. Congruently the [ $\beta$ ] are differentiative design moves which discriminate and select the appropriate [A]. Although the overall process is sequential, the steps leading to [B] and ultimately [AD] are iterative spiral loops. I expand on this aspect of the process by proposing the change [C] and boundary conserving [D] agents. Together, the alpha and beta along with the change and conserving agents work to produce creative design solutions.

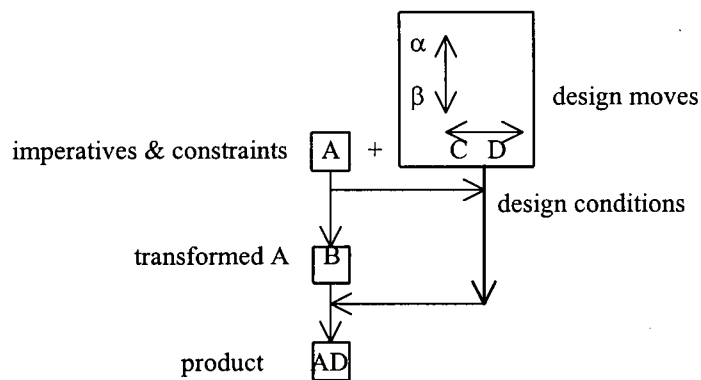


FIGURE 8 PAGANI'S DESIGN PROCESS FRAMEWORK

The change agents give rise to contingent design-moves, “order from noise”, and the conservation agents give rise to forced design-moves, “order from order”. Both contingent and forced design-moves are necessary to develop good designs which fit the design imperatives [A].

In his most recent work, Holland (1998) shows how early computer programs modeled checker playing. The programs were able to ‘learn’ from experience by assigning weightings to moves and changing the weights based on evaluation of the moves in retrospect. This points up the importance of the [A] that the design team are dealing with. If the [A] does not include ecological constraints then the design will not respond to them. Further the weightings given to the different project parameters will not be revised to reflect success if the criteria for success related to ecological issues is not clear to the design team.

I propose that there is a dynamic aspect to the interaction between the integrative and differentiative modes (FIGURE 9). When change agents “push the boundaries” of the boundary conservation agents this leads to the alpha and beta boundary-breaking vehicles working to develop re-integration and ‘insight’ for the phenomenon under consideration. As shown in FIGURE 4 on page 46, for the design process the change agents are information, inspiration and intention. Conserving agents are kenos (ordered units of knowledge), motivation and operation. When the designer oscillates between change agents and

conservation agents and pushes from differentiation to integration there is a dynamic equilibrium and steady progress towards the goal. When the designer is brought to a state of 'chaos' by a major change agent, the energy required to formulate a major reintegration results in a 'click' of insight. These clicks occur continuously through the design process to a greater or lesser degree. Minor clicks may be as simple as the moment of seeing the site as part of a valley as opposed to a set of contour lines. Major clicks are rare and lead to breakthroughs such as a spatial ordering diagram which allows the constraints of program, site and climate to be addressed simultaneously.

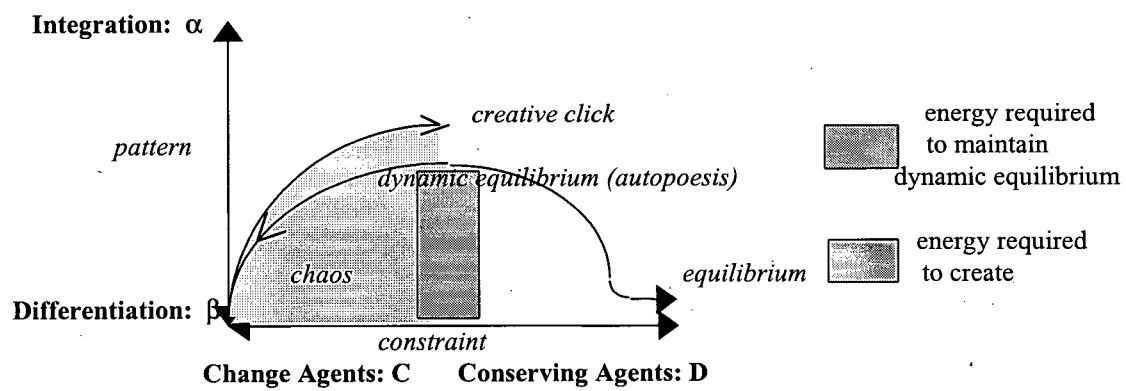


FIGURE 9 THE DYNAMICS OF DESIGN PROCESS

### 2.3.3.5 The Proposed Project Design Process

The group has a distinct advantage over the individual because ideas can become personal property or one's own intellectual territory. The strength of that territory is considerable, and the difficulty of working alone is often in the breaking of the bonds caused by it. With a group the bonds are broken more easily, because the critical faculty is depersonalized.

Richard Burton quoted in Lawson (1994)

Complexity can be made tractable by identifying empirical levels of organization in a system and observing their interactions. Complexity is defined by Ahl and Allen as "an apparent connection between fine-grain structure and behaviour and large-scale structure and behaviour. Large-scale behaviour

corresponds to events widely separated in space or time, which are nonetheless coherent” and “complexity requires that a link be made between details and context, but...separate levels function in a remarkably autonomous fashion” (Ahl & Allen 1996, 85). In the project delivery process, the organizational levels are: first, individual design process and second, project team group process.

At the latter level, the overall project delivery process can be viewed as a cumulative and collaborative set of individual design processes (as modeled in the previous section) with each participant ‘designing’ their particular aspect of the overall process. The user ‘designs’ the statement of needs and desires; the planner ‘designs’ the statement of the community requirements; the architect ‘designs’ the formal and material aspects of the building; the mechanical engineer ‘designs’ the servicing of the building with tempered air and water; the electrical engineer ‘designs’ the servicing of the building with light and power; the contractor ‘designs’ the process of constructing the design; the building operator ‘designs’ the maintenance and operating processes.

Lawson has investigated design process by interviewing designers. He observes that designers talk about “the thrill one gets from a group activity, which cannot be replicated through individual effort. This particular frisson is known, for example, to those who play music in groups or part of a sports team, and seems to come from the very fact that the group is able to perform together as a result of some understanding which they share but which may not necessarily be made explicit to others outside the group” (Lawson 1994, 30).

It is crucial that relevant *information* be available to the team early in the process. Research to develop knowledge of the user’s needs, the site, the community and the ecosystem is essential. The specialist information that is held by the various team players must be shared in order to allow the maximum input to each individual designer but especially to the architect who is the integrative agent for the overall design product. Traditionally, the architect leads the design process (described in Chapter 1) with the sub-consultant expertise being applied after the architectural design has been fixed. I argue that a more evolutionary process should require early collaborative and formative input from all the traditional participants and should seek early input from non-traditional participants such as the building operators,

users or local heritage groups in order to enrich and extend the opportunities for developing responsive designs. Recent work in the C-2000 Canadian federal government energy efficiency program for commercial buildings has demonstrated that the initial step of involving engineers in the early schematic design stages has significant benefit from the point of view of energy saving (Coady 1995). A critical voice in the existing process that is missing is a spokesperson for the needs of the ecology of the site.

*Inspiration* must be present for the entire team as well as the individual designers. The client or the project manager can provide inspiration for the team. Inspired individuals can achieve small gains but the group must be jointly inspired in order for emergent creative gains to be made. Some recent initiatives in design/build have been successful mainly because the inspiration motivating the designer and the contractor is shared.

In order for the individual design processes to make a creative and meaningful whole at this next level of organization, all the participants must formulate joint *intentions*. The group must be responsive to each others needs and objectives. A set of project objectives should be developed jointly by the participants. This will lead to a common 'meta-intention'. "Partnering" is a current development in project delivery in which the individuals involved in a project develop joint objectives at the outset and formally agree to work towards them in the implementation of the project. Partnering initiatives have been quite successful in bringing complex fast track projects to a favorable conclusion.

A project manager (who might be an architect) should lead the participants through the joint and individual 'design' processes to ensure that information, inspiration and intention are shared by the team members.

## **2.4 Natural Evolutionary Dynamics**

In natural systems, variation occurs through sexual reproduction where genes combine to produce new entities. In addition, mutation in the genetic structure of individual organisms will be introduced to and passed on within a species through the mechanisms of reproduction. Mutation is a random change in gene or number of chromosomes and is the ultimate origin of all new inheritable variation (Bullock,

Stalleybrass, et al. 1988). Agents that cause mutations are mutagens and among the most potent are various chemicals and types of ionizing radiation (Fried 1990).

In natural systems, selection occurs when particular characteristics of species, which are well suited to their environmental conditions, ensure survival of those members of the species which possess those characteristics (adaptation). Phenotypic plasticity confers survival advantage as it allows new behaviours to develop in response to changing conditions. Epigenesis imparts spatial and temporal order on developing genes and allows adaptive development (Strohman 1997). Disturbances in natural systems bring in new conditions for members of an ecosystem and lead to developmental changes, e.g. a forest fire leads to changed soil conditions which nurture the growth of different species so that regeneration occurs. This natural resilience allows ecosystems to evolve. Major disasters have led to punctuated equilibrium (Vrba & Gould 1986) resulting in the development of new species.

The system moves through a regime of dynamic equilibrium between minor variation and resulting adaptation. When major variations occur, the process of selection acts to weed out the less fit. The process of emergence acts to create new wholes that are then retained and become adapted. This is known as survival of the fittest.

## ***2.5 The Design Process Framework Dynamics***

For me, architecture continually swings between extremes and takes definite shape only when I will it to do so...I am subject to a tension in which confidence and insecurity are blended. In creating works of architecture, I continually waver between such extremes.

The greater the amplitude of these swings during the process of design, the greater the dynamism apparent in the finished product.

Tadao Ando

If one considers the project delivery and design process to be a series of problems that require resolution then key components of these processes are problem finding and problem solving. Grossman & Wiseman (1993) define problem solving as bringing into being a new idea that is a bridge between a present situation and some preferred future state. For them problem definition or redefinition is often contained within a

proposed solution. This is very similar to notions of paradox resolution where a new overarching framework is required to resolve the seemingly opposing ideas contained in the paradox. I suggest that project delivery and design process can be considered as a nested series of problems that are more or less creatively solved by the team both jointly and individually.

In terms of the design process (see *FIGURE 9*), an individual may swing wildly between the extremes of *equilibrium* and *instability threshold*, may tread water in the centre in a steady state of *dynamic equilibrium* (autopoiesis) or may consistently exhibit a bias toward one extreme or the other, which can result in an 'unfit' product. In the first case, conditions are created for instability whereby a leap to the equivalent of a *dissipative structure* can be achieved. This "click" or leap to an insight, a new idea, a complete hypothesis or a breakthrough is the realization of a more generalized framework that permits resolution of dilemma or paradox. It is the problem-solving bridge between the present state and the preferred future state. The pleasurable feelings that accompany "clicks" are the result of the dissipation of the tension that comes from the perceived paradox prior to the "click".

Restak notes this dualism in the brain: "The brain has evolved into an inherently dialectic organ that attempts during every moment of its existence to achieve a unification of opposites. Thought and emotion, art and science, yin and yang, the literal and the metaphorical, the true and the illusory - these are only some of the dualisms that this inherently dualistic organ wrestles with. And the advantage of such an arrangement? One hemisphere acts as a corrective for the other" (Restak 1995, 101). Ornstein also notes the dialectic nature of the brain: "[t]he right side doesn't (mystically) somehow perceive things whole, but seems to be specialized for the large elements of perception...the left side handles the small, precise links that carry the smaller, more precise meanings and movements. It's this specialization that contributes to one side being good for the analysis of the small elements versus the synthesis or holistic vision, or language via the literal meaning versus the intonation and indirect meaning. I still like text and context." (Ornstein 1997, 175)

## **2.6 The Role of the Change Agents, Boundary Conserving Agents and Boundary Breaking Vehicles**

Though the creative event appears discontinuous and transcendent, the process may be evolutionary and incremental. Stephen Grossman

The highest forms of originality are far more closely akin to the lowest biotic performances than the external circumstances would indicate. Michael Polanyi

In many nonlinear systems, there is an equation of motion called the control parameter that contains a numerical parameter that functions to control the complexity of a system. Control parameters move a system through its various states by adjustment of variables. They are like a tuning knob or a tap that controls the flow of water. The control parameters are what I have called the change agents.

The change agents in design process are identified in FIGURE 4 (page 46). The values for the change agents vary with the degree of relevant environmental input. This is analogous to the input of energy in a thermodynamic system. As the values of the variables increase the designer's efficiency, effectiveness and creativeness is increased. A critical question is what controls the interaction or dynamics of the variables. How can the design process be made more efficient, effective and creative? I believe that deliberate intervention from an outside force that provides high values for the variables of the change agents will accomplish this end. The outside force may be accidental (a book, a walk in the forest) but may also be a facilitator who deliberately presents the variables to a project team.

The design process control parameters will adjust an individual's level of response to environmental inputs. The more concentrated or obvious the change agents, the more responsive will be the individual's output. Further, the control parameters form a nested hierarchy and I believe all three must be present to result in a design product that is truly responsive to environmental issues. The levels of control act in either direction: i.e. top-down or bottom-up. Without relevant information, attempts to address environmental issues will be futile or even destructive. Without inspiration, there will be no motivation to address environmental issues. Without visionary intention, there will be no setting of relevant goals and striving to achieve them.

The three parameters are related directly to the three psychological domains of the cognitive, affective and volitional (Torrance & Rockenstein 1988).

The process of looking for a career is an example of an act that requires all three control parameters. Information on the necessary qualifications, the openings available and the degree of competition must be available. Information is a necessary but insufficient parameter. People also require an emotional push: inspiration. For some this will come from knowing someone who has a similar job and loves it. For others it will come from the necessity of unemployment or employment that is unrewarding. Again, inspiration is a necessary but insufficient parameter. The final condition necessary to achieve the desired result is the intention to carry out the demanding task. The intention may be formulated and carried out through "the final straw of an incident in the present job" or through the threat of losing a coveted new car. Through a combination of information, inspiration and intention a new career can be found.

I will first describe the control parameters (the change agents), then the boundary-conservation agents and finally the boundary-breaking vehicles.

## **2.6.1 The Change Agents**

### **2.6.1.1 Information**

The act of knowing includes an appraisal; and this personal coefficient, which shapes all factual knowledge, bridges in doing so the disjunction between subjectivity and objectivity. It implies the claim that man can transcend his own subjectivity by striving passionately to fulfill his personal obligations to universal standards. Michael Polanyi

Information is one input which an organism takes from the environment to help it deal with maintaining life. Energy is another. Information can also be considered as negentropy or the ordering force that counteracts the tendency of all systems to move towards disordered states (Boulding 1977). In fact, information can be defined mathematically as negative entropy (Bullock, Stalleybrass, et al. 1988). Berlyne has shown experimentally that 'too much' information from the environment leads to feelings of discomfort in humans (Berlyne 1971). Kaplan and Kaplan have developed a Preference Matrix of informational characteristics that allows researchers to explain characteristics of preferred environments.

The matrix has four informational factors: complexity; coherence; mystery; and legibility. Preferred environments call for “a modicum of the qualities that permit immediate processing” of the information contained in a scene. Their findings show that human preference for specific environments seems to be intimately related to effective functioning which is evidenced in feelings of increased safety, comfort and competence (Kaplan & Kaplan 1989).

Amabile notes that there is some evidence that exposure to a wide array of information can enhance creativity (Amabile 1983, 71).

Chalmers suggests that the basic psycho-physical laws centrally involve the concept of information. He puts forward a hypothesis. “Perhaps information, or at least some information, has two basic aspects: a physical one and an experiential one” (Chalmers 1995). As discussed in a previous section, I suggest that humans process information through synthesis and analysis which, according to D’Aquili and Mol, Rose, and several others, occurs in the right and left hemispheres of the brain. “In the furtherance of receptivity toward stimuli, the nondominant [right] hemisphere...fuses disparate elements syncretistically into recognizable wholes within a context...the dominant hemisphere, separates, discriminates, details, and focuses...embracing everything and knowing nothing is the opposite of knowing everything and comprehending nothing” (Rose 1992). “Research ...has demonstrated beyond a doubt that the dominant (usually left) hemisphere of the brain is intimately involved both with language functions and sequential, analytical thinking. The non-dominant or right side of the brain...has been shown to control gestalt perceptions, and generally is responsible for those aspects of mentation which involve the perception or construction of the environment as a whole or a number of wholes” (d’Aquili & Mol 1990).

As I have shown in FIGURE 4 on page 46, I propose that in design systems, variation similar to that in natural systems occurs through the input of novel information. At the first level of design systems, the confirming (adapted) action of the “*kenes*” (existing knowledge) prevents the novel information from being overwhelming and pushing the mind into ‘chaos’ (see Figure 8, page 78). The change agent of *information* activates the boundary-breaking vehicles of synthesis and analysis and as the mind moves between them it attempts to incorporate the new information into its existing knowledge structure. An especially novel

piece of information (a change agent equivalent to a mutation) will push the mind into a 'chaotic' mode which will then require a significant reorganization of concepts using a process of selection and a concomitant amount of energy (or effort) to bring out an emergent concept. The new organization of the mind then settles back into a movement between synthesis and analysis of incoming and existing information. There is a continuing process of integration and differentiation acting on the change and boundary-conservation agents (information and knowledge). For example, if a child reads a book about adoption it may work through an analysis of its own relationship to its parents, reorganize its 'kenes' (what it knows) about parent/child relationships and then reach a new synthesis about parental love or its relationship to its own parents.

Berlyne (1971) developed a theory of the appreciation of art or beauty which states that maximum satisfaction will occur when there is a balance between two factors related to the information contained in the object of appreciation: multiplicity/variety/complexity and unity/order/lawfulness. He conducted experiments where the subjects were asked to rate enjoyment from viewing or listening to works of art of various degrees of combinations of simple/familiar, simple/novel, complex/familiar and complex/novel. He confirmed experimentally that maximum satisfaction was derived from the combinations of simple/novel and complex/familiar. The extremes of simple/familiar and complex/novel resulted in minimal arousal (or boredom) and maximum arousal (or anxiety). Berlyne postulates that the primary reward system of the brain is stimulated to result in pleasure by a moderate arousal increase. Increase of arousal followed by relief brings the secondary reward system into play. Relief inhibits the aversion system and indirectly releases the gratifying effects of the primary reward system (Berlyne 1971).

Rothenberg (1979) has extended Berlyne's concept of gratification from perception of balanced external stimuli to gratification for an individual who produces balanced stimuli. In other words a combination of simple/novel and complex/familiar thoughts will be most satisfying. Amabile has also noted the importance of environmental scanning to creative performance (Amabile 1983). Environmental scanning is the deliberate broadening of the focus of attention for short periods of time. It provides novel information in manageable amounts.

The presence of novel information is only part of the requirement for creativity. Known and predictable information (knowledge) is also important. When the two are fused, a new level of emergent information is present. New patterns can be perceived and made.

Just as the combination of the two sets of parents' genes will lead to a unique genetic offspring, so I propose that the combination of novel information and kenos will lead to a unique emergent output.

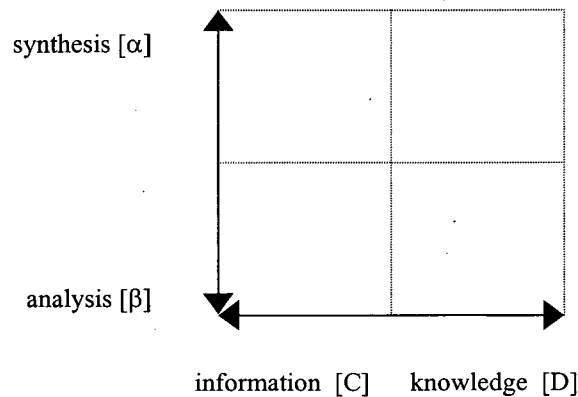


FIGURE 10 INFORMATION IN DESIGN SYSTEMS

### 2.6.1.2 Inspiration

No profit grows where is no pleasure taken, in short, study what thou dost affect.

Shakespeare

Shakespeare used *affect* (from the Latin word *affectare* 'to aim') in the above quote in the sense of a natural tendency towards a thing. Inspiration comes from the Latin word *inspirare* 'to breathe into' and the Funk and Wagnalls dictionary definition is "the infusion or arousal within the mind of some idea, feeling or impulse, especially one that leads to creative action".

The change agent of *inspiration* activates the movement between primary and secondary processes. Primary process is internal motivation activated through non-rational processes of the mind and secondary process is external motivation activated through the rational processes of the mind. Inspiration produces variety and motivation selects appropriate variety. Dynamic equilibrium comes from the oscillation

between these two agents. A shift to a new level of complexity comes from invention introduced through inspiration and integrated into the motivation to conform to a desired end. An illustrative example is the development of an individual style in art. A good artist can develop a personal style that is so strong that it is easily identifiable. Style comes from deep internal personal tendencies and is developed more cohesively over successive works. Each work is a struggle between the incorporation of new ideas and the maintenance of the coherence of the individual style. Primary and secondary process (feeling and rationality) work on the inspiration and motivation to attain new levels of complexity. Purely idiosyncratic response to fashion quickly becomes self-indulgent unless it is tempered by the more lasting concerns of the development of a coherent personal style.

People can be inspired by coming across exemplary models of values that they uphold. Hearing about the good work of Mother Theresa can impart the energy necessary for someone to change the focus of their own life. Other sources of inspiration are: coming across beauty, aesthetic contemplation, religious conviction, or immersion in nature.

Literally, inspiration is the act of drawing in the breath. The dictionary definition is *the infusion or arousal within the mind of some idea, feeling, or impulse, especially one that leads to creative action* (Landau 1968). Inspiration leads to goal commitment, which is crucial for achieving difficult goals (Hollenbeck, Klein, et al. 1989). Goal setting is discussed under intention but the inter-relationship between commitment and goal-setting is critical. "The primary consequence of goal commitment is to moderate the relation between goal difficulty and task performance" (Hollenbeck, Klein, et al. 1989). Kuhn and Geis (1985) have developed a theory that states that individual creativity is directly related to organizational commitment. While their theory is specifically focused on organizational commitment, it is applicable to individual commitment in the temporary organization of a project team. They define commitment as the link between personal meaning and organizational mission; "the emotional lines of force that attracts individuals to institutions, the psychic energy that maintains physical presence and mental membership" (Kuhn & Geis 1985). Inspiration can be self-determined or controlled, i.e., the regulation is experienced as being freely chosen (self-determined) versus being compelled or pressured by some external force

(controlled). When self-determined, people tend to display greater creativity, more cognitive flexibility and higher satisfaction and trust. Self-determination theory proposes three fundamental psychological needs as energizers of behaviour: the needs for competence, relatedness, and self-determination (autonomy) (Deci 1992). These needs mediate the person's relationship to the environment.

Inspiration is the equivalent to Polanyi's concept of heuristic passion which is "the mainspring of originality - the force which impels us to abandon an accepted framework of interpretation and commit ourselves, by the crossing of a logical gap, to the use of a new framework" (Polanyi 1962).

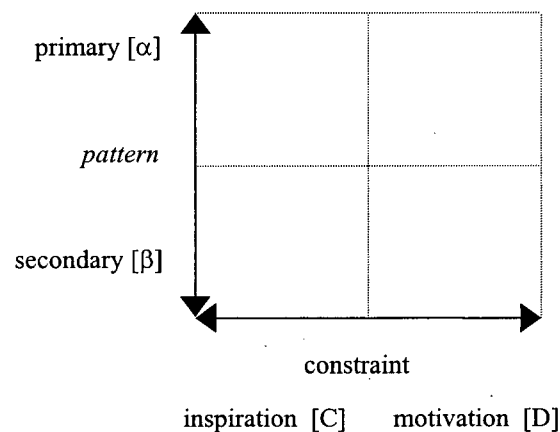


FIGURE 11 INSPIRATION IN DESIGN SYSTEMS

### 2.6.1.3 Intention

[I]ntention is different from the representing desire, on which it builds...a subject desires when he has a goal...but the subject intends when he also has a plan to satisfy his goal.

Joseph Bogdan

Intention is a *purpose; aim; or goal* from the Latin *to stretch out* (Landau 1968).

Intention is one mechanism by which intuitive or reflective environmental responses can be 'bootstrapped' to become innovative. Intention operates by focusing attention on specific areas of perception. Humans reaction to perception of the environment is either intuitive (innate) or reflective (learned). Both types of

reactions have value for survival. "Nonlearned and acquired cooperation are adaptive responses of animals defending their integrity in a changing environment. Both nature and nurture... have their distinct but also complementary contribution to make to adaptation" (d'Aquili & Mol 1990). The dictionary definition of intuition is: *a direct knowledge or awareness of something without conscious attention or reasoning; nonintellectual perception or apprehension* (Landau 1968).

Goal setting and task performance theory illuminate the function of intention. An individual who has set a goal "has to choose to take action in accordance with each chosen goal by keeping in focal awareness what is to be achieved, the means needed to achieve it, and the reasons for or benefits of such action" (Locke & Latham 1990). Goal setting theory shows that assigned goals facilitate performance because they influence both self-efficacy and personal goals. More difficult goals are seen to be more instrumental in attaining valued outcomes than easier goals. Goals affect performance in three ways: first, they energize performance by motivating the person to exert effort in line with the difficulty or demands of the task; second, they motivate individuals to persist in their activities through time; third, if they are clear and specific, they direct the individual's attention to relevant behaviours or outcomes and even affect how information is processed. These mechanisms of "effort, persistence and direction of attention operate virtually automatically once there is a commitment to the goal and the individual decides to act to achieve it" (ibid., 94, 95). Feedback or knowledge of results is an important component of the goal-performance relationship (Carson & Carson 1993).

In their teaching/learning model called Sensational Thinking, O'Neill and Shallcross hypothesize that perception is a naturally occurring dynamic system and that it constitutes a creative process containing the characteristics of inclusion, self-similarity and feedback. The model acknowledges the presence of paradox and the need for collaborative interaction and shows five stages of information processing. These are Readiness (purposeful intention), Reception (receptive awareness), Reflection (reflective attention), Revelation (emergent pattern), and Re-creation (expression/manifestation). The authors believe the model is useful for helping educators to support and guide efforts to increase perceptual functions and as a diagnostic tool. "Our perceptual functions naturally balance ambiguity and boundaries, however when we

impose a cognitive function, the result is a barrier. Allowing perceptual function to inform conceptual function frees our innate problem solving abilities" (O'Neill & Shallcross 1994).

A problem can be seen as a gap between where we are now and where we would like to be at some point in the future when the problem is solved (Grossman & Wiseman 1993). The development of an idea of a future state must consequently play a significant role in the eventual productivity of the problem solving process. The image of the future plays a role as a guidepost, organizing and focusing ideas. For Boulding (1977, 173), the image is made up of images of fact and images of value and the raw material of both is messages. Subjective or internal messages may play a large part in developing our images of fact and messages from nature may play a large part in developing our image of fact. However, Boulding says by far the greater part of our image is built up from symbolic messages from transcripts or teachers. The image is built up as a result of all the past experiences of the possessor of the image. This subjective knowledge is what guides our instinctive responses to situations and is commonly called intuition.

Calatrava, a structural engineer who is also an architect, talks about the role of the 'central idea' in design process. He speaks of the idea being not inside but outside him as some sort of distant light which offers a target or focus for the process (Lawson 1994, 30)

Setting goals provides a mechanism for contributing to the development of an image. Most people derive satisfaction from setting goals and achieving them. Once a goal is reached satisfaction diminishes quickly. The pleasure seems mainly to be in the "hunt". Goals encourage performance beyond the norm. They become a 'crane' for heightening performance. Dennett uses the term crane to describe "a special feature of a design process that can be demonstrated to permit the local speeding up of the basic, slow process of natural selection and that can be demonstrated to be itself the predictable (or retrospectively explicable) product of the basic process" (Dennett 1995, 76).

The boundary breaking vehicles are movement between intuition and reflection. This is the mechanism for learning (Holland 1998, Schon 1983). We do something, reflect on its effect and adjust our doing to suit the desired outcome. The activity is incremental and goal-directed. By this recursive means we improve our performance until it becomes intuitive. Further change is achieved by further reflection bringing new

levels of complexity. It takes a significant shock to the system to effect a major change. Critical feedback is a device for effecting change in design and collective development of new precedent. Major changes result in revelation and transcendence to new orders of organization. The chaos out of which the transcendence emerges will either cause a shift to a new approach or a retreat to the familiar old precedents. This can be experienced by those who have been seriously ill or in a life-threatening accident. Such people are often transformed by the experience and change the course of their lives by reexamining their goals.

In organisms, developmentally flexible adaptation occurs when an organism changes its behaviour in response to a change in the environment. In creativity the image is the mechanism for inducing changes in behaviour. "[G]oals, especially if they are clear and specific, direct the individual's attention to relevant behaviours or outcomes and even affect how information is processed" (Locke & Latham 1990).

As Polanyi has said: "Unopposed, the circumstances of a commitment would overwhelm and wipe out the impulse of commitment; but a centre actively committing itself resists and limits these circumstances to the point of turning them into instruments of its own operations." (Polanyi 1962, 397)

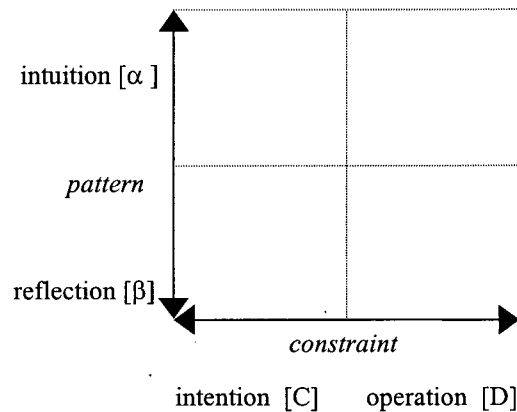


FIGURE 12 INTENTION IN DESIGN SYSTEMS

### **2.6.2 The Boundary-Conserving Agents**

Change agents can be seen as ways of achieving variation in systems. They are the mechanisms which jumpstart the process of innovation. Boundary-conservation agents can be seen as ways of maintaining stability. In Jantsch's terms these are novelty and confirmation.

Just as evolution 'selects out' certain genetic variations which do not 'fit' the environment well, so the mind appears to work in a similar way, 'selecting' certain patterns of information, inspiration and intention which then become the knowledge, motivation and operation which form the boundaries for an individual's frame of reference. And just as evolution produces variety through random mutation and genetic variation, so the mind produces variety through scanning and novelty seeking behaviour.

"Randomness coupled with a selection or recognition process yields purpose" (Grossman 1994).

#### **2.6.2.1 Knowledge**

Our knowledge of phenomena is complete only when it has reached that point at which everything that seemed to be a boundary becomes a transition, and we suddenly become aware of the relativity of the whole.

Wilhelm Worringer

Pattern recognition can be argued to be the central factor in discovery in science. Patterns such as faces and musical tunes are recognized instantly from among thousands of others. As well as the ability to recognize concrete patterns, people have the ability to recognize more abstract patterns, i.e., those without visual or auditory content. These patterns consist of networks of relationships between facts, assumptions, mathematical relations and methods, measurement techniques, rules of thumb and hunches. A discovery involves expansion, rearrangement or simplification of all or part of this network. A pattern, or the absence of a pattern where one is expected, or a defect in an existing pattern is noted by the brain, i.e., it is selected. Elaboration takes place, i.e., it is varied as required to make sense in a larger context. A theory is developed to explain the observed pattern and the theory may also be elaborated (or varied). Experimental testing then takes place (Loehle 1994).

Polanyi suggests that ordering principles exist which we are able to recognize both subjectively and objectively. "[D]ynamic interaction between order and randomness is a necessary and sufficient condition

for the applicability of probability statements to mechanical systems (Polanyi 1962, 39). Polanyi believes that this also applies to natural systems. Humans have a capacity for recognizing randomness from order in nature. We can recognize pattern and we are particularly attuned to recognizing changes in familiar patterns.

Boulding says that the process of increasing knowledge is anti-entropic. It builds structure out of what was perceived as chaos and organizes the disorganized (Boulding 1977, 130). The organized knowledge represents a boundary conserving condition for an individual.

#### **2.6.2.2 Motivation**

At the second level of design systems, I propose that selection similar to natural systems occurs through *motivation*. Motivation is a need or drive for a certain end. Input that is perceived as not helping to lead to the desired end is rejected.

Amabile (1983) hypothesizes that the intrinsically motivated state is conducive to creativity, whereas the extrinsically motivated state is somewhat detrimental to creativity. Many writers on creativity have noted that creative processes are often accompanied by feelings of fun, joy or even ecstasy. It can be speculated that since humans depend on processing information from the environment for survival that this activity would be of high importance and would therefore, like sexual reproduction, be expected to generate positive feelings.

Amabile defines intrinsic motivation as being experienced when people engage in an activity primarily out of their own interest in it. Extrinsic motivation is experienced when people engage in an activity in order to obtain external rewards like money or prestige.

Amabile notes that evaluation of creative performance can have detrimental effects on performance whereas technical performance is less significantly affected (1983, 117). She notes also that there is a consistent positive relationship between expressed interest in an activity and actual creativity of performance (1983, 137).

On the basis of sociological, archival, and experimental research, Amabile concludes that creativity may be socially transmitted through modeling: “an exposure to creative models early in one’s professional development can have a positive impact on early creative achievement”. She also found that “motivational orientation towards one’s work (which could be socially transmitted through modeling) has an important impact on creativity” (1983, 157).

Maslow has pointed out that self-actualizing individuals, after they have met their basic needs, are motivated on a “higher” level of achieving in order to meet needs beyond the basic (metamotivation). These individuals are often devoted to some mission or “call” in life for which they seem particularly suited. At this level the dichotomy between work and play is transcended (Maslow 1986).

Just as internal motivation is critical for individual high quality task performance, external motivation is also critical. While an individual project team member may have high internal commitment to environmental issues, unless the entire team is energized and has been explicitly charged with addressing environmental issues and given the time and/or financial resources needed to carry out the task then the individual’s internal commitment can be easily thwarted. Such a broad charge can only come from the client of a project. Lawson has noted the importance of the client to the architect. “Many of the designers in this book emphasize the importance of the client in the design process” and “The extent to which the client is committed to the project is clearly thought to be critical to the success of the process. Michael Wilford believes that ‘behind every distinctive building is an equally distinctive client’ ”(Lawson 1994, 136). Dana Cuff also states that excellent architecture requires excellent clients as well as excellent architects (Cuff 1992, 232).

#### ***2.6.2.3 Operation***

Self-reliance, which supports us to meet the indeterminate contingencies of  
commitment...makes us ready to suppress a routine operation of the mind in favour of a  
novel impulse.

Michael Polanyi

The bootstrapping effect of intention can be brought about by: force of circumstance (there seems to be no other way out), the threat of a negative outcome if an action is not taken, or the clear formulation of a goal or target.

At the third level of design systems, the formation of *operations* in the mind is equivalent to speciation in natural systems. These are the 'habits' of the mind and they are very resistant to change. Once humans learn how to do something it is very hard for them to learn a different approach. Operationalizing our dealings with the environment enables us to rely on learnt responses that have worked for us in the past. Indeed, research has shown that repeatedly used synapses in the brain develop stronger connections and are therefore more readily activated. So it seems that there is a physiological basis for the easy activation of operations that are repeated. For example, when we find ourselves on 'automatic pilot' when driving to work we can speculate that these strongly connected synapses are firing according to the well-worn path of perception of a familiar route. The driving sequence has become operationalized. Having tested and reliable ways of dealing with the world makes it easier for an organism to navigate in a changing and unreliable world. However it also means that changing these routine responses to situations is very difficult. The will to break the habit must be present in order to overcome the strong in-built tendency to revert to a habitual response to a situation.

### **2.6.3 The Boundary-Breaking Vehicles**

What you do very often is you face the reality for certain moments and then you say 'to heck with the reality' and you do the fantastic and you go back and forth.

Robert Venturi

Imagination deserted by reason produces impossible monsters: united with her, she is the mother of the arts and the source of all their marvels.

Francisco de Goya y Lucientes

The boundary-breaking vehicles are the means by which a system moves from a 'part' oriented position to a 'whole' oriented position. The vehicles are called boundary-breaking because they are the means by which a system breaks the boundaries between the part and the whole. The change agent is the catalyst for the boundary-breaking vehicles to come into operation. The boundary conservation agents are the means by which the system maintains stability and autonomy. To break the boundary between one level of a system and another requires a great deal of effort and a reorganization of the parts. This third dimension of the framework is shown in FIGURE 13.

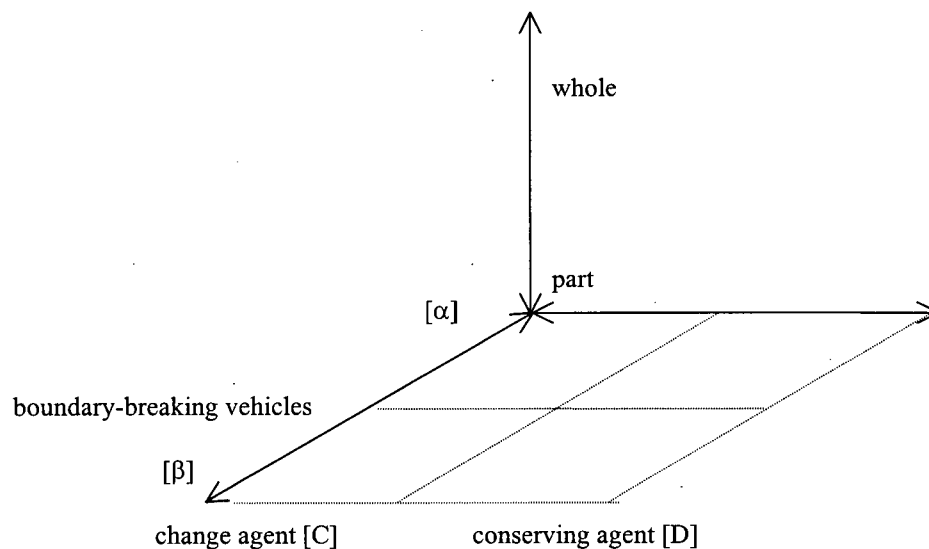


FIGURE 13 THE THIRD DIMENSION OF THE COMPLEX ADAPTIVE SYSTEM FRAMEWORK

The law of requisite variety is a fundamental principle in systems theory. It outlines how a system regulates itself, sometimes opening up to complexity and sometimes reducing variety. Creativity seems to follow a similar principle as it moves between divergent and convergent thinking (Rickards 1993). Several authors (notably Debono, Adams, Osborn, and Gordon) have developed techniques for the promotion of divergent thinking. Divergent techniques in cognitive processing such as fluency (production of many ideas) and flexibility (variations of one idea) are keys in the generation of multiple connections between remote objects. Since most creativity research has focused on developing techniques to assist in

the development of divergence skills, the equally important skill of convergence has been given little attention. Other authors have pointed out the need for a discussion of the process of convergence in creative thinking. “The selection, refinement and use [original emphasis] of images spontaneously generated during transitional or altered states likely may depend upon effortful executive processes” (Flowers and Garbin quoted in Daniels-McGhee & Davis 1994).

For Grossman (1994) randomness coupled with a selection or recognition process yields purpose. He says “it is important to note that neither randomness nor algorithms for selection by themselves are significant. It is the two in consort that may be the powerful mechanism to explain what seems, at the macro level, to be discontinuous leaps or transcendence”. Grossman goes on to point out that randomizing ideas is not an easy task for the brain and states that recent brain research suggests that randomization is in fact at cross-purposes to normal brain function. In an effort to overcome this inherent limitation, techniques for randomizing ideas have been developed by de Bono (1985) and Adams (1986). Most of these techniques require deferred judgment when output is being generated. However, the exercise of judgment is a necessary next phase as the ‘varied’ output gets sifted and selected for relevance to the nature of the problem. This involves a process of comparison of the varied outputs to the original objectives or intentions in order to assess the potential for the output to meet or exceed the objectives. These processes of *differentiation* of inputs and *integration* of them into known wholes make up what I have called the boundary-breaking vehicles. The differentiation processes are selective and reductive and the integrative processes are generative and emergent.

In the project design process, the ‘kenes’ are the known, ordered data related to the site, the ecology, the community, the users and the client. Random elements of data may occur naturally as the project progresses and it is up to the team to seize the opportunity for incorporating both types of data into the context of the project and transforming it into information. The last minute changes in or additions to the requirements of a client often provide the momentum for a change in the design that improves the overall quality.

Grossman and Wiseman describe the key process factor in creativity as the ability to find common bonds between two or more previously unconnected ideas or concepts. Grossman and Wiseman propose that less time in problem solving be devoted to the production of many ideas and that more focused and time limited production of ideas should occur. Emphasis should then be placed on a more protracted convergence phase (Grossman & Wiseman 1993). Discrimination and judgment are the key qualities for convergence.

When Richard Feynman talked about his methods of doing science he emphasized not freedom but constraints. "Scientific creativity is imagination in a straitjacket" (Gleick 1992, 324). Similarly, the architect, Richard Burton, moves back and forth between the relevant constraints (having first carefully prepared the necessary information and expertise) while not allowing any particular constraint to become dominant (Lawson 1994, 16).

In the project design process, convergent and divergent thinking can be provided by the various members of the team. The early involvement of subconsultants encourages the possibility for both divergence through brainstorming and convergence through critical selective feedback for the coordinating designer. Similar variety and selective feedback can come from the client and from community participation.

### ***2.6.3.1 Synthetical and Analytical***

There's the poet and the artist on one side and the technician on the other and this is a good metaphor for what we're up to as architects. The danger is when you see only the technical man, or the artist who doesn't have any practical skills. I see the architect as right in the middle trying to hold these two together in a kind of harmony, and if he gets it right it produces almost another dimension, and if you go into such a building you say "ah that's it".

Richard Burton

Analysis is the breaking of a whole into its constituent parts. Synthesis is the pulling together of parts to make a whole. In each case the parts can be thought of as patterns of information that are being perceived by an individual. The patterns are perceived and manipulated by the brain. New patterns can be formed when the parts are recombined in different ways. Most of us can relate to the idea of information overload. Too much irrelevant information creates confusion and/or concern. Most of us can also relate to the

frustration of boredom. Stimulus deprivation studies have shown that too little information leads to hallucination and disorientation. Appropriate amounts of relevant information are crucial for healthy, functioning individuals.

Therefore it is crucial that in order to reach optimum levels of achievement, the project delivery team have available to them the means to obtain sufficient relevant environmental information. They must be aware of as many sources as possible and must seek the information at the appropriate time in the process. From my experience, to achieve best results relevant information is most critical to the entire team at the early stages of design, particularly the information and expertise of the specialist subconsultants. This is contrary to conventional practice in which the architect will often produce the building design alone and then pass it to the subconsultants for them to 'make it work'. At this late point the specialist's knowledge is very restricted in its ability to be applied constructively.

In a study of design decision-making in architectural practice, the authors found that "architects would appear to have largely ignored much of the information available...[they have a] tendency to rely on memory and direct experience" (Mackinder & Marvin 1982). While I am not aware of any studies that have been carried out, my experience has been that engineers appear to work in the opposite way. They will place precedence on quantitative information often at the expense of qualitative experiential information. This suggests that early collaboration between architects and engineers would improve the quality of the design.

Brian Lawson in a series of interviews with well known architects, found reference to the processes of analysis and synthesis. "We have now recognized that designers often come to understand their problems through their attempts to solve them. We might call this analysis through synthesis. Laboratory experiments conducted by the author have shown that students of design gradually develop cognitive strategies based upon this procedure, whereas students of natural sciences do not" (Lawson 1994). Thus Robert Venturi lays emphasis on a design process that works from the particular to the general as much as the other way round. Richard Burton "likes to shift very quickly between all the relevant constraints, and

this involves very careful preparation in terms of assembling the necessary information and expertise”  
(Lawson 1994).

### ***2.6.3.2 Primary and Secondary***

We should take care not to make the intellect our god; it has, of course, powerful  
muscles but no personality.

Albert Einstein

God guard me from those thoughts men think  
In the mind alone;  
He that sings a lasting song  
Thinks in a marrow-bone.

William Butler Yeats

I propose that intrinsic motivation exists when the primary processes of the mind engage in the task.  
“Mental contents arranged under the primary process are under high tension, seeking immediate discharge, and are subject to condensation and displacement without regard to logical separations. Mental processes arranged under the secondary processes are under low tension, capable of delayed discharge and follow logical principles of precise discrimination” (Rose 1992, 9). Rose elaborates primary processes as involving ambiguity, perceiving time and space as fused and undifferentiated and as being related to feelings and impulses. Maslow calls the primary processes poetic, metaphoric, mystic, primitive, archaic, childlike (1986). Secondary processes involve control, perceive time and space as separate and discrete and are related to logical, defined thoughts (Rose 1992). Primary process operates on the pleasure principle, secondary process operates on the reality principle. Extrinsic motivation exists when the secondary process is engaged. Inspiration activates intrinsic and extrinsic motivation to develop creative responses to design problems and results in commitment.

Just as physiological versatility involves a physiological organismic response to an external stimulus which allows an adaptation to a local circumstance, so I propose that internal motivation provides the additional drive that an external stimulus such as financial or social recognition can initiate or vice versa.

Based on the work of several authors, I propose that internal motivation comes about when the primary processes of the mind are engaged. Similarly, external motivation comes about when the secondary

processes of the mind are engaged. Freud was the first to make the distinction between primary process and secondary process. He identified primary process as stemming from primordial mechanisms which emerge spontaneously in humans when they are overcome by emotions, prejudice or anger or when they are indoctrinated by mores or cultural habits. These processes have been labeled "primitive, immature, obsolete, archaic, dedifferentiated, abnormal, defective, first-signaling, concrete, and mythic" (Arieti 1976). Several authors have stressed the critical role that primary process thinking plays in creativity: Arieti (1976); Gustafson & Norlander (1994); Rose (1992); and Rothbart (1972). Access to primary process cognition is through what Rothbart calls the preconscious state when the organism is off-guard, relaxed and receptive to its own messages. The individual lets things happen instead of trying to direct impulses in accordance with established patterns of thought and habit. The architect, Michael Wilford says of design: "One is bringing to bear an unconscious body of attitudes and experience in that decision-making process. I can make it sound very pragmatic, and actually it is, but the pragmatics are guided or conditioned by this other layer of concern in the subconscious that is very difficult to articulate" (Lawson 1994, 112).

Preconscious states include dreaming, daydreaming, fantasizing and being in light hypnotic trances. Hallucinogenic drugs also may provide access to a preconscious state. The material produced by the primary process needs to be transformed by the secondary process. The secondary process is concerned with the perception and interpretation of external reality and is marked by alert concentration on a task or idea. It abstracts and discriminates following logical principles. Einstein said that genius is 1% inspiration and 99% perspiration. Inspiration is essential but it must be supported by motivation to support the hard work entailed in bringing an inspiration to fruition.

### ***2.6.3.3 Intuitive and Reflective***

To develop a vision which brings the inner and outer worlds together, we need common roots once more. We are like Antaeus of old, whose strength, ebbing whenever he lost contact with the Earth, his mother, became renewed each time he touched the ground. Spun out of our heads, science and art remain anemic and without root, and need strengthening contact with nature once again.

Gyorgy Kepes

'I find there are these very hot moments as it were when things happen very quickly...I think it's rather like juggling actually, you know one couldn't juggle very slowly over a long period.' MacCormac recognizes alternating phases of quite different types of cognition in his design process, with 'periods of reflection and criticism' separating the periods of more rapid and intense thought 'which throw out propositions'.

Brian Lawson quoting Richard MacCormac

When I hear people say they will never be successful, I believe they are probably right.

Henry Ford

Reflection-in-action is a mechanism for building skill in professional practice through description of intuitive understanding (Schon 1983). Without reflection-in-action intuitive understandings remain tacit, but without second order reflection learning is constrained to lower order learning and possibilities for meta level learning are short circuited. "If we separate thinking from doing, seeing thought only as a preparation for action and action only as an implementation of thought, then it is easy to believe that when we step into the separate domain of thought we will become lost in an infinite regress of thinking about thinking. But, in actual reflection-in-action...doing and thinking are complementary" (ibid., 280).

Intuitive actions come about as a result of many repetitions of a behaviour. Neurobiologists have shown that repetition of a behaviour results in a strengthening of the connections between the neurons in the brain (Edelman 1992). Reflective actions involve the breaking of habitual behaviours or thought processes.

When we learn how to ride a bike we practice until we get the 'feel' of bicycling. Once we have the feel of

riding a bike it is very difficult to describe to someone how we do it. We have developed tacit knowledge and have difficulty making such knowledge explicit.

The intuitive mode involves allowing perceptions that come from the senses to 'inform' the reflective (thinking) mode. James Gleick said of Richard Feynman that "those who watched Feynman in moments of intense concentration came away with a strong, even disturbing sense of the physicality of the process, as though his brain did not stop with the gray matter but extended through every muscle in his body" (Gleick 1993). Feynman himself said that Einstein's great work had sprung from physical intuition.

In the project delivery and design process the carrying out of the intentions must be both intuitive (i.e. involving experiential, empirical and subjective perceptions) and reflective (i.e. involving intellectual, rational, objective perceptions). Just as in nature the conserving agent is heredity, in building projects the conserving agent is precedent or typology. Architects study the 'solutions' to similar architectural problems and apply these precedents in new situations. However, if precedent alone was used there would be no change. It is through the processes of reflection and critical feedback that change is possible.

Criticism can come from professional critics in journals and newspapers, from historians or from teachers in the design studio (Attoe 1978). The word criticism comes from the Greek *krinein* meaning to separate or make distinctions. It is the change agent for precedent to evolve and adapt to changing circumstances. Criticism has a focus on how events in the past can teach us how to handle future similar events.

"[A]lways there should be what might be called an evolutionary bias in criticism" (Attoe 1978, 163).

In the project design process critical feedback is crucial as the design develops. Having the subconsultants involved all through the design will give opportunities for feedback, but user and public feedback is also important.

Adams (1986), in the introduction to his book The Care and Feeding of Ideas: A Guide to Encouraging Creativity outlines his basic thesis: that the production of ideas occurs as a result of focused energy and effort and that this focus can be achieved through specific processes (such as setting targets). The purpose of these processes is to move us away from thinking in programmed and predictable ways.

Our individual subjective experience is stored in our minds as a sum of personal feelings, thoughts, images, and impressions. There is also an objective reality that lies outside our subjective experience. I contend that the setting of specific targets that lie outside our immediate experience allows us to draw creatively on our subjective experience to build realistic constructs without actual experience as we strive to meet the targets. To do this we need to overcome certain habits of thought (Adams 1986).

Prioritized and/or quantified targets help to objectify decisions and lead to less subjective/habitual decision-making (Adams 1986). Boulding has said "facts are objective and values are subjective....the raw material of our image, both of fact and value, is messages" (Boulding 1977, 173). For him, communication and feedback are the sources for orderly and organized growth.

## **2.7 Statement of the Problem and Research Questions**

A predominantly Darwinian attitude toward design would emphasize the generation of variety, the creation of a broad spectrum of chances for innovation in the physical, social, and spiritual realms...a kind of enablement which aids them in their natural way of self-balancing and lets them find and build structures instead of imposing structures on processes.

Erich Jantsch

Having reviewed the literature related to design as a complex adaptive system, discussed creativity as a component of design and outlined a design process framework based on the processes of complex adaptive systems, I now outline the research questions which are addressed in the dissertation.

### **2.7.1 The Underlying Hypothesis**

Since evolutionary processes have resulted in products that: 'fit' their function; that reciprocate with their environment; that are both elegantly efficient and appropriately redundant and; that further are incredibly beautiful while being both typical and idiosyncratic, then a design process which follows similar processes and which is used by all the participants in the project design process will result in products with similar qualities. Further, the processes of complex adaptive systems are themselves 'design' processes and a theory of design process may be developed from them.

I propose that linking the design process to environmental (economic, social and ecological) issues through *information, inspiration and intention* will result in adaptive products. The change agents of information, inspiration and intention intensify the boundary-breaking vehicles of the *synthetic/analytic, primary/secondary, and intuitive/reflective* processes. Change agents push a designer to a new level of complexity in the system of design process. A distinction is made here between the level of scale of complexity in the design process that is marked by change agents which push the designer to higher order processes and change agents which push the designer to a new level of complexity in the design itself. It is important to maintain this distinction between the design process and the design (which is a product of that process). The building itself is the ultimate product of the design. The building, the design and the design process (and the design process of design process) are levels in a scale from concrete to abstract. The building is the concrete expression of the design (which is represented by the abstractions of models and drawings) and the design is the result of the even more abstract process of design (which is represented here by the abstraction of words and diagrams).

The design process framework that I have developed has within it levels of control in a scale from particular to general (FIGURE 4, page 46). At the particular level the process is dealing with specific information. At the next level the process is dealing with inspiration of a specific nature but not as particular in its application. At the third level the process is dealing with general objectives.

Evolution is a special case of adaptation. If evolution leads to well adapted products, then an evolutionary design process will lead to well adapted products. Design is a complex adaptive system. Complex systems are systems where fine details are linked to large outcomes (Ahl & Allen 1996). Adaptive systems interact with their environment and change in response to environmental change (Clayton & Radcliffe 1996).

By studying the general processes of complex adaptive systems we can learn more about design process. Holland (1995) points out that in complex adaptive systems "a small input can produce major, predictable, directed changes - an amplifier effect" (1995, 5). The predictability referred to is an overall predictability. For example, in weather there are predictable overall patterns but unpredictable detail happenings. Holland

cites vaccine as an example. The vaccine ‘levers’ the immune system into learning about a disease.

Locating similar levers for the design process will make it more efficient.

The dissertation develops a synthesized theoretical framework from the literature and experiential knowledge. This framework is “tested” as described in Chapters 3 and 4. Financial and time constraints necessitated the development of a protocol that focuses on certain aspects of the framework. The intention is not so much to verify the universality of the Pagani model but rather to see how it describes or elaborates on system behaviour. The process is, in fact, very much the process described in the dissertation and the exploration seeks affirmation of the hypothesis through a process which may be loosely termed triangulation. It is recognized that not all instances of design can display exactly the same characteristics so it would be impossible to find absolute verification of a singular process. Rather the author seeks to validate the idea that certain conditions in the design process will result in more adaptive products. The dissertation process is (like any design process) iterative and subject to new insights and “clicks” and I have recorded the most significant of these as faithfully as possible.

The dissertation addresses the following research questions:

**Research Question #1:**

*Does a framework for project delivery and design process that uses the processes of complex adaptive systems provide a useful tool for practitioners?*

**Research Question #2:**

*Does a project delivery and design process that uses the processes of complex adaptive systems result in buildings or designs that are well adapted to their environment?*

**Research Question #3:**

*Does a project delivery and design process that uses the processes of complex adaptive systems result in buildings or designs that are more creative?*

#### **Research Question #4:**

*Does oscillation between the change and conserving agents and movement between the boundary breaking vehicles lead to creative breakthroughs?*

The dissertation develops a framework for a project delivery and design process model and tests it in two case studies: an actual project delivery and a simulation of a project design in an educational setting. In order to answer the research questions the value of the framework will be tested in three ways. First, it will be assessed subjectively by designers for inherent utility, second, it will be assessed for its potential to affect the environmental outcomes of a design and, third, it will be assessed for its value in enhancing creativity. Indicators for success in the product resulting from the model framework are developed. If, according to the indicators, the product is more environmentally responsible and/or according to consensual assessment the product is more creative and/or more environmentally responsible, then research questions 2 and 3 will have been answered in the positive and suggestions for further research will be made. Research question 1 (the effectiveness of the framework as a tool for practitioners) and research question 4 (whether oscillation between the dimensions leads to enhanced creativity) will be investigated through subjective assessments from designers.

#### **2.7.2 Significance of the Hypothesis**

The hypothesis:

- provides a vehicle for designers to design more environmentally responsible products;
- provides a working tool for individuals and for design teams to enrich and expand the opportunities inherent in each project;
- provides a model that can be elaborated and used as a basis for further research in the area of design studies;
- provides a model for discussion and use in teaching design in the design studio;

- provides a framework for extending the discussion of design into disciplines not presently discussing it explicitly, notably the engineering professions.

Case studies were undertaken to address the four research questions. Chapter 3 describes the design of the studies, the methodologies developed and the procedures used for measurement and assessment.

## **Chapter 3**

# **Tough-Minded and Tender-Minded**

## ***The Analytical Framework***

### **3.1 Introduction**

So what should we do to investigate design? Quite simply we must do all we can. There is a role for philosophizing about design, we can learn from observation, we might get insight from experiments, and we should be foolish indeed not to try to ask designers how they do it.

Brian Lawson

In this chapter, I outline the overall approach to the research. I describe the design of a trial, a pilot study and four case studies (a project case study, a project design simulation, a design simulation and an interview with a practicing professional) which address the research questions developed in Chapter 2. The participants and procedures are described in this Chapter, as well as the procedures for evaluating the data. The results will be discussed in Chapter 4.

### **3.2 The Approach to the Research**

A constructionist interpretation of studies is based on purposive (theoretical) sampling, grounded theory, inductive data analysis, and idiographic (contextual) interpretations. Trustworthiness of the interpretation rests on four components: *credibility*, *transferability*, *dependability* and *confirmability* (Denzin 1994).

This approach draws on the two traditions of research design: the positivist and the phenomenological. It incorporates their beliefs and methods: the world is both external and objective as well as socially constructed and subjective; the observer is independent as well as part of what is observed; focus on facts as well as meanings; reductionism as well as holism; measurement of operationalized concepts as well as use of multiple methods to establish different views of the phenomena (Easterby-Smith, Thorpe, et al. 1991).

In studying creativity, Isaksen et al have adopted an interactionist approach. "Our goal is to understand the natural interactions among the sources that lead to creative productivity. We believe that too many previous investigations have artificially separated creativity, for analytical or experimental simplicity or convenience, into separate or isolated topics of study" (Isaksen, Puccio, et al. 1993, 156). I am investigating the interactions between design process, project design process, and design product. Therefore the analysis will focus on three levels in a hierarchy: the individual process, the group process, and the product. At each level I will seek to identify 'levers' which activate the change agents and to assess whether the boundary breaking vehicles had a role in effecting the change. Research questions 1 (*Does a framework for project delivery and design process that uses the processes of complex adaptive systems provide a useful tool for practitioners?*) and 4 (*Does oscillation between the change and conserving agents and movement between the boundary breaking vehicles lead to creative breakthroughs?*) deal with the individual and the group processes and questions 2 (*Does a project delivery and design process that uses the processes of complex adaptive systems result in buildings or designs that are well adapted to their environment?*) and 3 (*Does a project delivery and design process that uses the processes of complex adaptive systems result in buildings or designs that are more creative?*) deal with the product.

The investigations concern evolutionary processes in the individual design process and in the group process and their combined effect on the environmental fit of the product. In order to measure the fit of the product to its economic, social and ecological context a set of indicators is developed. The indicators assess the economic, social and ecological impact of a building.

Denzin suggests that two interpretive communities exist: the tough-minded and the tender-minded. The tough-minded: are hard-nosed empiricists, are rational and cognitive, treat interpretations as a method, value neutrality and the canons of good science. The tender-minded: are intuitive and emotional, exhibit personal biases, treat interpretation as an art, value antirealism, and view science as power (Denzin 1994). I use both these frameworks for the design of the studies.

This approach necessitates using convergence as the method for seeking confirmation. Data is triangulated whenever possible so that a single source is not relied on for results. Multiple methods are used to address

the four research questions: case study, questionnaires, analysis of self-reflection records, analysis of interview records, consensual assessment and indicator assessment. A summary is given in

TABLE 1.

	Building Case Study	Seminar in Sustainable Design	Design Simulation	Designer Interview
<b>Question #1:</b> Does a framework for project delivery and design process which uses the processes of CAS provide a useful tool for practitioners?	Debriefing Session	Questionnaires		Interview Analysis
<b>Question #2:</b> Does a project delivery and design process that uses the processes of CAS result in buildings or designs that are well adapted to their environment?	Indicators	Consensual Assessment, Indicators, Design Diaries		Interview Analysis
<b>Question #3:</b> Does a project delivery and design process that uses the processes of CAS result in buildings or designs that are more creative?		Consensual Assessment, Design Diaries, Questionnaires		Interview Analysis
<b>Question #4:</b> Does oscillation between the change and conserving agents and movement between the boundary breaking vehicles lead to creative breakthroughs?		Questionnaires & Design Diaries	Recording of think aloud protocol	Interview Analysis

TABLE 1 THE RESEARCH QUESTIONS AND STUDIES

### ***3.3 The Study Designs, Methods and Measures***

Multiple methods were used to establish different views of the phenomenon and four studies were undertaken: first, a case study of an actual project, second, a project design simulation to test the framework proposed by the author, third, a simulation of a design process for protocol analysis and, fourth, an interview with a respected designer on aspects of design process. I will describe the designs, methods and data analysis for each study individually. Lastly, I will describe a pilot project and a trial study that were undertaken prior to the project design simulation in order to refine the design and methods.

### 3.3.1 The Project Case Study

#### 3.3.1.1 The Design of the Study

Case studies are an appropriate research method for answering “how” questions about contemporary events where there is access to documents, artifacts, interviews and observations (Yin 1989, 18 - 20). While case studies are not generalizable to populations or universes they are generalizable to theoretical propositions (Yin 1989, 21). “[T]he essence of a case study...is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result” (Schramm quoted in Yin 1989, 23).

The purpose of the project case study is: to determine whether the subject project can be legitimately classified as a well adapted building; to determine and investigate the process innovations which occurred; and to determine their contribution to the success of the building as an adaptive building. This study addresses research question #2: *does a project delivery and design process that uses the processes of complex adaptive systems result in buildings that are well adapted to their environment?*

The case study is an actual built project on the campus of the University of British Columbia (Building B). The project was completed in 1996 under the direction of the author who, at the time, was Associate Director, Project Development in Campus Planning and Development. As a result of a personal commitment by the author and subsequent ratification by senior administration, it was decided to establish the building as a benchmark in the development of approaches to sustainable design. Since its completion it has won three awards and been published in journals, newspapers and books and as a significant ‘green’ building.

The building consists of 3,000 square meters of office, research and seminar space and sits on a long narrow site running north and south with a dense coniferous forest on the west side and a street on the east side. The final design included such innovations as composting toilets, a projected savings in energy use of approximately 40% less than a standard building of the same type, a constructed wetland drainage and purification system for the compost liquid and grey water, a storm water storage system for irrigation, significant quantities of re-used and recycled materials, and an overall reduction in material intensity. The

first significant difference in this project was the client commitment to develop a demonstration building. The second difference was that the project team for Building B (owners, users, architect, landscape architect, structural, mechanical and electrical engineers) attended a workshop at the outset of the project. The workshop was facilitated by an architect who had recently devoted his career to encouraging the architectural profession to design more environmentally responsible buildings. Led by this architect (Bob Berkebile, who had suffered a great tragedy when a building of his design had collapsed) the team shared memories of events of significance in their own lives. Subsequently with examples of recent projects as models, the team developed an explicit set of environmental objectives, quantified where possible, for the building including: using recycled materials; using re-used materials; reducing energy use by 50% over ASHRAE 90.1 (a demanding energy standard developed by the American Society of Heating, Refrigeration and Air-conditioning Engineers); maximizing natural ventilation and daylighting; no sewer connection; reducing water use. The third significant departure from normal project process was the deliberate inclusion of the subconsultants by the architect during all stages of the design.

The case study employs a set of indicators developed by the author to compare the subject building to another building of a similar size, age, location and use (Building A). The background and rationale for the indicators is attached in Appendix 1. The project design process is analyzed using reflection and feedback from the project participants to extract the salient differences from the normal process.

### ***3.3.1.2 The Method***

In order to determine whether the building was indeed a significantly better environmental fit than other similar buildings, a comparison of two buildings on the campus of the University of British Columbia was undertaken using the indicators. Building A (the comparison building) and Building B (the case study building) are both faculty office and classroom buildings of approximately the same age and size. The square foot budget figure for Building A was slightly lower than that for Building B. This was a factor unrelated to the project brief but rather related to differing budget priorities established by the university administration. Building A was designed to meet ASHRAE 90.1 (a high energy performance standard). The volume of Building B was slightly greater than Building A and the surface area to volume ratio was

greater due to the proportions of the site. This difference meant that energy savings were more difficult to achieve for Building B. At the same time, access to interior daylight and fresh air was easier. Both buildings were required to meet the university technical standards with specific exceptions made for building B where the design adopted strategies based on the objectives developed at the start of the project.

The table below summarizes basic statistics for the two buildings.

	<b>Building A</b>	<b>Building B</b>
Number of occupants	65 full-time	90 full-time
Net square feet	17,000	17,500
Gross square feet	32,000	30,000
Gross sq. ft./full-time person	492	333
Capital construction cost	\$130/sq. ft.	\$150/sq. ft.
Lighting electrical demand	1.8 watts/sq. ft.	0.9 watts/sq. ft.
Ventilation	20 cfm/person	20 cfm/person
Water use (estimate only)	x	x-1000 gallons/day
Operating energy GJ/yr	1008	755
Operating energy GJ/sq. ft./yr	.031	.025
Operating energy GJ/person/yr	16.8	8.38

TABLE 2 COMPARISON OF BUILDINGS A AND B

After Building B was completed and had been in operation for a year, a meeting of the project team (including consultants, contractors, users and operators) was convened by the owner and each member of the team was asked to say what they believed were the three most and the three least successful aspects of the project. The responses were recorded in writing. The information gleaned from this session was interpreted in light of the fact that the participants may have had a vested interest in providing positive feedback and that all the data obtained was subjective in nature. However since the comments solicited were based on judgments of the most and least successful aspects of the project I do not consider the potential for a degree of compromise in the responses to be of significant concern. The key purpose in using the session as part of the case study is to determine which aspects of the project design process were

considered by the participants to be different than a normal project and, in their judgment, which of the differences were the most important. The differences are analyzed for their similarity to the processes of complex adaptive systems.

### ***3.3.1.3 The Measures***

To measure the adaptiveness of the building, the economic impacts, social impacts and major energy and resource flows of the two buildings are assessed and compared using the indicators. The author uses her own reflective thought to analyze the key differences between this project and the others (approximately 25) carried out under her direction on the campus in an eight year time frame. This is supplemented by verbal feedback from the project team at the post project debriefing session.

This study is designed to measure the effect of evolutionary process innovations on the adaptiveness of the product.

## **3.3.2 The Project Design Simulation Study**

### ***3.3.2.1 The Design of the Study***

The project design simulation study was designed to address all four research questions.

The simulation is a correlational pretest, posttest research design. The design simulation was carried out at the School of Architecture at the University of British Columbia. A seminar course titled Seminar in Sustainable Design was offered to all design students, i.e. those in architecture, engineering, landscape architecture and planning. In order to ensure that the model was also tested by practicing professionals, the course was offered jointly to the members of the local architects, landscape architects, engineers and planners professional associations. To assess the design process framework for effectiveness in increasing environmental fit in the product, students were asked to prepare schematic designs before and after lectures and practice sessions with the design process framework. The designs were assessed for environmental fit using the indicators and using consensual assessment. In order to assess the usefulness of the framework to designers a questionnaire was issued immediately after both designs were completed. In order to assess the value of the framework in assisting creativity, participants were asked to keep design diaries during both design sessions. Finally, consensual assessment by experts was used to assess the designs for creativity.

The purpose of any experimental design is to control variance, i.e. to maximize the systematic variance caused by the independent variable and to control extraneous sources of systematic variance as well as minimize error variance by controlling the circumstances under which the experiment is conducted (Amabile & Stubbs 1982). As the number of subjects in the simulation (24) was insufficient for statistical validity, the study does not seek to make causal inferences regarding the relationships among the variables. Rather, conclusions drawn from the simulation are inferred from the underlying theory (Rudestam and Newton). Internal validity in the study was enhanced by randomly assigning participants to experimental and control conditions. External validity was enhanced by minimizing extraneous variables by developing a computer program for use as a pedagogical tool. The program has the potential to be used outside the classroom as a tool for practicing architects.

The independent variables are the control parameters: *information, inspiration and intention*. The dependent variable is the *adaptiveness* (the environmental fit) of the design product. The moderating variable (the conditions under which an independent variable exerts its effects on the dependent variable i.e. 'when') is movement between the *integration* and *differentiation* capacities and the *change agents* and *conservation agents*. The independent variables and the moderating variable are complex adaptive systems processes.

The independent and moderating variables were manipulated through lectures, discussions and practice sessions using the techniques described in the computer program. Students in a school of architecture undergo design simulations in order to learn design process. The manipulations involved in testing the design process model are very close to the normal activities of the design studio setting.

FIGURE 14 shows the conceptual design of the study. The participants were assigned to six groups of 4 -5 with an even mix of students and practitioners as well as disciplines. Each group was given 12 hours to design a building without any instructions or information other than the normal program and site information. The groups were then randomly assigned to control and experimental groups. The author, through lectures, performed the independent variable manipulations for all participants. Additionally, through separate practice sessions using two different versions of an interactive web page (one of which

contained the framework and the creativity techniques and one of which contained only the creativity techniques) the moderating variable was manipulated with the experimental group. The two sets of groups (control and experimental) were then asked to redesign the facility using the same program and site.

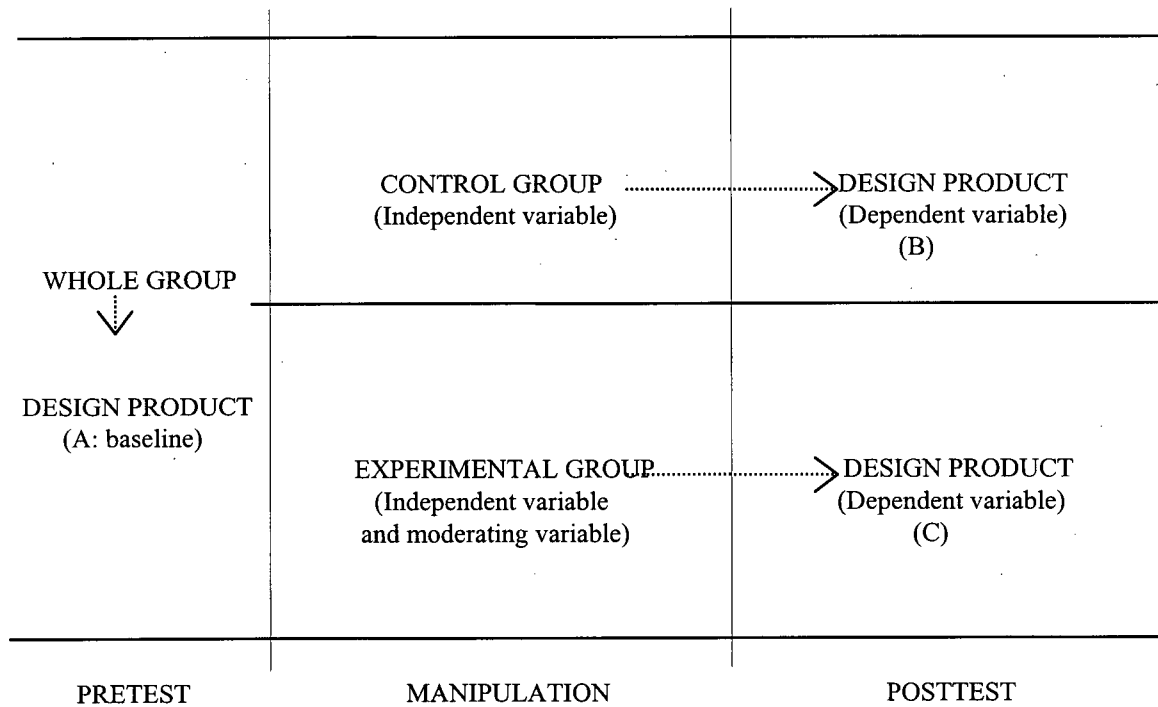


FIGURE 14 THE STRUCTURE OF THE PROJECT DELIVERY AND DESIGN SIMULATION

### 3.3.2.2 The Participants

Participants in the simulation were self-selected second and third year master's degree students in the School of Architecture, and undergraduate students in the Landscape Architecture Program and the School of Community and Regional Planning at the University of British Columbia. No students from the Engineering Departments in Applied Science registered. The students represent a convenience sample of designers who have some basic design skills and who were likely to be responsive to the independent variable manipulations involved in the study. In all, 14 students registered for the course and two subsequently dropped out. Of the remaining 12, 5 were architecture students, 3 were planning students and 4 were landscape architecture students. The consent letter that was given to participants is included in Appendix 2.2.

In order to provide more credibility and confirmability, design professionals were recruited through advertising with professional associations. Of the 13 professionals who registered, 8 were architects and 5 were planners. The course advertisement is included in Appendix 2.1.

Since the subject of the course was sustainable design, a bias toward that subject in the self-selected participants must be assumed. It is not felt that this bias skews the results of the assessments of the designs as the final measure is a comparison between a pretest and a posttest set of designs. If any effect resulted from this bias it would have been mitigation of the effect of the inspiration and intention variable manipulations.

### ***3.3.2.3 The Method of the Study***

According to Amabile (1982) research methods lie on a continuum of experimental rigour (expressing the degree of control the experimenter has over the variables) from case studies, to action research, to correlational research, to quasi-experimental research and finally to true experimental research. The project delivery and design simulation lies between action research and quasi-experimental research. There are some variables over which there can be no control: the skill of the designers, interpersonal dynamics, the degree of experience of the designer, etc. However, the choice of a group all working on the same design gives control over the external variables of client, site, program, climate etc. A facilitator undertook the manipulations of the variables in the different cases. The facilitator (the author) is an experienced architect and educator with a prolonged engagement in the field and who has pursued what Lincoln and Guba (1985) call persistent observation of the phenomena under consideration. This provides a degree of credibility and dependability to the study. Further credibility will come from triangulation in the results obtained from employing different methods of data collection. Transferability is provided by the publication (on a compact disc - see Appendix 3) of the model along with specific techniques for employing the process. Confirmability will come from further testing.

The study was carried out in a seminar on sustainable design taught by the author. The course was a forty hour, six week course with two three-hour classes per week and two ten-hour design workshops in the first and fifth weeks in lieu of two of the evening sessions.

An interactive computer module (Appendix 3) was developed which describes the techniques that the participants were asked to employ during the manipulations. Two versions were developed: one that provides only the techniques, and one that, in addition, provides an explicit model showing the moderating variable. The first module was used for the control group and the second for the experimental group.

The first five weeks of classes were organized with a one hour lecture on sustainable design, one hour of discussion and one hour of self-learning and practicing the techniques in a computer laboratory. The trial group and the experimental group worked in separate areas of the computer laboratory using two different versions of the self-learning computer program.

Participants were asked to record their design decisions at 15-minute intervals in a diary with preprinted sheets and the experimental group were asked in addition to record their position on a diagram of the design process model at the same intervals.

After the introductory class a one-day design workshop was held. Participants were organized into groups with balanced student and professional representation and balanced representation from the different disciplines. At the outset the groups were given names selected randomly from a dictionary (Gram Molecule, Atlas Mountains, Full-blown, Blood, Stoneware, Halve). Prior to the posttest workshop the groups were asked to incorporate the essence of their name into their design. This was an attempt to provide each group with random information.

The groups were given a project brief for a design problem (see Appendix 2.3) and directed to develop a schematic design. The following two evening classes were also assigned to design time for a total of 12 hours. The groups were asked to elect a 'project manager'. No other special instructions were given to any participants. The designs were collected at the end of the workshop portion of the classes for later assessment. In the last half-hour the participants were asked to fill out a questionnaire related to their design decision-making.

The next two weeks of classes involved the manipulation of the independent variables: information, inspiration and intention. Participants received information through lectures, assigned readings and

discussions and use of the techniques. Inspiration was given through the lectures and through use of the techniques. Intention was formed through use of the techniques and through a specific goal setting exercise related to the design problem: groups were asked to establish three objectives related to sustainability prior to starting on the posttest design.

In the fifth and sixth weeks the second design workshop was held. The same teams were asked to redesign the same design problem that was given in the first week. As before, a questionnaire was given in the last half-hour and the designs were collected for subsequent assessment. In order to correct for the time the groups spent in familiarizing themselves with the site and the program during the first workshop, two hours were subtracted from the total time available for redesign. Those two hours were taken up by talks from representatives of the proposed building owners and users in order to reinforce the information and inspiration variables.

In the sixth week participants used the indicators to assess the designs produced at the first and second workshops for economic, social and ecological 'fit' (see Appendix 2.4). Additionally, an independent group of eleven invited experts (4 architects, 2 landscape architects, 3 engineers, a planner and a user representative) carried out consensual assessment of the designs for sustainability, creativity, technical competence and aesthetic value. All the experts except the user representative and one engineer (the owner representative) had a special expertise in sustainable issues in design. The designs were hung on the wall in a room in a random order. Participants verbally described the designs with instructions not to give any indication of which design was done first. The experts were each given sheets with a different random order in which to view the designs and were asked to rank order the twelve designs in four categories: sustainability, technical competence, creativeness and aesthetic value (Appendix 2.5). The results are discussed in Chapter 4.

#### ***3.3.2.4 The Data Analysis***

In the project design simulation the dependent variable is the environmental fit of the design.

Measurement of the dependent variable is first, by independent assessment using micro and meso level indicators (Appendix 1) in order to assess the response of the design to economic, social and ecological

issues and second, by consensual assessment of the product (Amabile 1983). The moderating variables are movement between integration/differentiation and change agents/conserving agents. Measurement of the effectiveness of the moderating variable is by: first, a subjective assessment of the value of the framework by the participants in the design tutorial; and second, by consensual assessment of the product for creativity (Amabile 1983).

Consensual assessment was developed by Amabile to address problems of creativity assessment in social psychology. Tests for creativity fall into categories of personality inventories, biographical inventories and behavioural assessments. Amabile questions the reliability of these tests. First, the construct validity of many of the tests has been seriously questioned by recent empirical work. Second, many of the tests measure a narrow range of abilities and Amabile questions their use for general assessments of creativity. Third, many of the tests use subjective scoring procedures. The prime caution against using creativity tests in empirical research is that they are developed as tools for measurement of individual differences. They are therefore inappropriate for use in experimental studies of social and environmental influences on creativity (Amabile 1983, 20-26). As the hypotheses under study are not related to personality, biography or behavioural factors creativity tests will not be used as a measure.

In developing consensual assessment as a methodology for assessing creativity Amabile makes explicit a definition of creativity which underlies most subjective creativity assessment methodologies:

“A product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated. Thus, creativity can be regarded as the quality of products or responses judged to be creative by appropriate observers, and it can also be regarded as the process by which something so judged is produced.”

(Amabile 1983, 31)

The emphasis here is that consensual definition is based on the product. Amabile points out that assessments based on process are not feasible given the current state psychological theory and research methodology. She argues that there is one form of creativity, one basic quality of products that people are

responding to when they call something 'creative', whether they are working in the arts or in science. Creativity is something that people can recognize and often agree upon without a guiding definition. Finally, she argues that there are degrees of creativity (Amabile 1983, 32).

The consensual assessment technique requires that the task in question leads to a product, that the task be open-ended and that there not be large differences in skill level when specific expertise is required to complete the task. Also, those who will make judgments as to levels of creativity should: all have experience in the domain in question and not be preselected by any other criteria; make their assessments independently; be asked to make other judgments such as technical and aesthetic capability; be asked to rate the products against one another rather than against an absolute standard and finally; be asked to view the products in a different random order (Amabile 1983, 38-39). All these conditions were met in the study. The best design is included in Appendix 5.

### **3.3.3 The Design Process Simulation**

#### ***3.3.3.1 The Design of the Study***

A nested study was undertaken during the Seminar in Sustainable Design. Individuals enrolled in the course were asked to design an object and to 'think aloud' while designing. The subjects were tape recorded with the intention of applying protocol analysis and linkography (Ericsson & Simon 1993), (Goldschmidt 1995). These analytical methods are explained in the data analysis section. Think aloud studies are important in investigating processes that are conducted internally. Asking subjects to continually verbalize their thoughts while they are designing is a valuable way to gain insight into the design process.

The purpose of the design process simulation study was to address research question #4: *does oscillation between the change and conserving agents and movement between the boundary breaking vehicles lead to creative breakthroughs?*

#### ***3.3.3.2 The Method of the Study***

During the course of the seminar, selected participants were asked to leave the group they were working with and take part in a think aloud protocol. The selection was based on availability with a preference for

experienced practitioners. Eight subjects took part. Instructions for the study were read to the participants. Emphasis was placed on the necessity for participants to keep verbalizing their thoughts constantly as they worked on a small design problem. The first three participants tackled the design of the front door to their group design. After one participant expressed concern over working on the design in isolation from the group and another indicated that the front door location was not yet finalized, the design problem was changed to the design of a rain protection device for a bicycle. Participants were given sketch tracing paper and a felt pen and asked to work on the design while thinking aloud. Tape recordings were made of their verbalizations.

### ***3.3.3.3 The Data Analysis***

For the design process simulation the analysis will be performed using protocol analysis and linkography.

Correlating the quality of a design with the quality of the process that brought it into being has been problematic (Goldschmidt 1995). Measures of efficiency are related to economy of thought. Expertise (the ability to take short cuts based on past experience) bears heavily on economy of thought in design. The amount of mental resources that are invested to obtain innovative ideas is directly related to creativity. Effectiveness is related to productivity. Goldschmidt (1995) accepts Wertheimer's definition of productive thinking being equivalent to productive designing because designing is a mode of thinking. For Wertheimer productive thinking occurs when it gives rise to genuine ideas, when it brings about a transition to understanding from a blind attitude. It is sharply different from rote understanding and following a prescribed course of action. It is this distinction that is important in differentiating between a design methodology and a design process. Since the degree of expertise among the groups of the participants is roughly equivalent, productivity will be the measure of the success of the design process.

Protocol analysis is aimed at facilitating access to cognitive aspects of the design process, particularly those related to productivity. A record of the design process is parsed into *moves* and the relationships created by the links among moves are examined. The notation system for the moves and the links is termed linkography. It is instrumental in comprehending structural patterns of design reasoning (Goldschmidt 1995). A design move is like a move in chess. It is a step, an act or an operation that transforms the

situation of the design relative to the situation prior to the move. In an individual process the moves are defined by discrete utterances in a think-aloud record. In a group process, utterances of an individual are design moves. Each move is numbered sequentially. A question is posed for each move: is it linked to every one of the moves that precede it in a given unit of the process? The criterion for determining linkage is common sense. Links between a move and its predecessors are termed *backlinks*. With the benefit of hindsight, links between a move and subsequent moves can be determined and are termed *forelinks*. Backlinks record the path that led to a move's generation and forelinks indicate the move's contribution to the production of further moves. "The number of links relative to the number of moves in a given sequence is an indicator of the 'strength' of the design process, or of its productivity." An effective design process is characterized by a high ratio of links between the moves. The proportion of links to moves is termed the Link Index (LI) and a correlation has been established between high LI values and productivity. Link intensive moves are called Critical Moves (CM) and the critical moves in a sequence describe its *critical path*. A quantified critical path comes about as a result of counting the CM's in a sequence and noting them as a percentage of the total design moves. If a move is rich in forelinks it is notated CM> and if it is rich in backlinks it is notated <CM. A Critical Move that is rich in both is notated <CM>. Quantifying is achieved by determining how many links are required to make a move a critical move. Goldschmidt chooses seven links to define the criticality of a move for three reasons: first, the grain of a study requires that the number of links be optimal for length of the critical path produced in order to give clear structural representation (too few will produce a long critical path); second, the number of links a designer is able to relate back to may well be associated with the number of discrete units of information a person can retain in their memory; third, empirical evidence shows that the lower the number of links the higher the %CM and that differences in % for different paths tend to converge on seven moves (Goldschmidt 1995).

### **3.3.4 The Interview**

#### ***3.3.4.1 The Design, Method and Measures of the Study***

The purpose of the interview was to address all four research questions and to use the subjective reflections of a practising designer for the purpose of gaining some objective correlation to the suppositions of the author regarding the nature of design process.

The interview was conducted with a mature, eminent design practitioner. The interview was informal, two hours long, with directed and open-ended questions about design process and about sustainable design (a copy of the questions is in Appendix 2.6). Written notes and tape recordings of the interview were made and qualitative analysis was undertaken. The author did not brief the designer on the nature of the study but merely requested her cooperation regarding a study of design process.

The results are discussed in Chapter 4.

### **3.4 The Trial**

A trial was undertaken to verify that the proposed manipulations in the design simulation realistically represent the independent and moderating variables. The author enlisted the help of a professional design team (the Colborne Group) willing to work with her to develop a schematic design for the project that was about to be undertaken in the pilot design tutorial. A one-hour briefing session and a three hour design simulation were held in the architect's office. The sessions were videotaped. Two expert observers (Doug Shadbolt, ex-Director of the School of Architecture and Moura Quayle, Director of the Landscape Architecture Program) were asked to verify that the manipulations and techniques were representative of the independent and moderating variables. Based on feedback from the experts adjustments were subsequently made to the model and the techniques.

### **3.5 The Pilot Study**

Each term professors in the School of Architecture (with assistance from adjunct professors) offer series of (five or so) design tutorials for which students sign up according to preference. Different topics are available and students are expected to experience a variety of topics as they progress through the school.

Tutorial classes will typically consist of twelve to sixteen students with varying levels of experience in design. Extra-session courses are offered in the spring and summer terms.

A presentation outlining the author's hypothesis was given to the staff at the school. Professors were requested to volunteer to allow the simulation to take place within their tutorial. One professor volunteered. The pilot study was conducted in a design tutorial in the fall term of 1996 in Tutorial 'T' at the School of Architecture, UBC. The tutorial topic was "tectonics" in architecture. Tectonics refers to the "art" of building where the physical and technical requirements of materials and systems are exploited to express or reveal their architectural qualities and thus contribute to the overall success of a design. The students work in drawings and models and are required to make a large-scale model representing a section through a wall in their design.

Since students randomly select themselves for the tutorials and they had no knowledge of the study when they signed up for the tutorial, there was no bias in the selection of the participants. Students within the tutorial were randomly assigned to a control group and an experimental group.

All subjects were given a non-specific outline of the objectives of the simulation. Students signed a consent form (copy attached in Appendix 2.7) which contained an agreement to take part in the simulation and to make use of the given techniques in the design. Students were given the freedom to opt out of the simulation if they felt it was hampering their ability to participate effectively in the design tutorial. One student took this option at the outset and was not included in the study.

The tutorial professors set the design problem and the output consisted of the schematic design for a small building. The duration of the design was five weeks and assessment of the student work occurred as normal by the professors. At the outset students were randomly assigned to a control group (7 students) and an experimental group (8 students). A facilitator (the author) worked with the experimental group to manipulate the variables. The manipulations were based on a series of techniques. These were presented to the students as a Toolbox for Designers (a copy is attached in Appendix 2.8). The facilitator conducted eight one-hour sessions with the experimental students where the techniques were practiced and applied to the design process. In order to reduce unintended bias in the professor's evaluations, the sessions were

conducted outside the design studio. The identity of the experimental group was therefore unknown to the professors. As a result the facilitator was remote from the day to day design moves of the experimental group and was unable to maintain control over the manipulations.

Students were asked to maintain a journal of their design process and were also asked to fill out a questionnaire after the manipulations were complete.

The School of Architecture provided all the previous written assessments and marks of the students in previous tutorials. The information was anonymous but divided into the control group and the experimental group. Average marks were determined for both groups. This provided an assessment of design ability so that any significant differences in design ability between the control group and the trial group could be accounted for in the assessment of the designs produced by the two groups.

### **3.5.1 Manipulation**

There were multiple manipulations for the independent variables (the three control parameters: *information; inspiration; intention*) and the moderating variables (*integration/differentiation and change agents/conservation agents*). Manipulation was achieved through a facilitator (the author). It should be noted that when the pilot study was undertaken the change agent and conserving agent moderating variables had not been identified.

In order to remove information on environmental issues in general as a moderating variable, all students in the tutorial were given a one half hour lecture and a paper by the author on current global environmental issues. Resource material relating to environmental issues was made equally available to all students. The control group received no further input from the facilitator.

The facilitator conducted eight one-hour sessions through the five weeks of the design. One student attended all eight sessions, three attended seven sessions, one attended six sessions, one attended five sessions and two attended four sessions. Limited informational input from architectural, engineering and landscape design professionals was made available to the trial students. Details are given below.

For the case of *information*, the facilitator made available to the trial students project-relevant information related to ecological, social and economic issues intended to develop their knowledge of the issues. A distinction is made between being aware of information related to issues and knowledge of the issues that can be applied to specific project situations. Under the moderating variable *synthetical* the techniques were Mind Mapping, Random Input, and Brainstorming. Under *analytical* the techniques were Analytical Drawing, the Lotus Blossom, and Energy Analysis. A mechanical engineer outlined a thermal calculation method that gives feedback on the energy use required by a particular schematic design. An architect demonstrated a computer program that analyses the social ordering of movement through space.

For the case of *inspiration* (termed motivation in the Toolbox), the facilitator engaged the imagination of the trial participants by sharing with them some of the specific environmental effects of recent buildings, such as the amount of resources consumed annually for construction and operation of buildings. The *primary* mode was activated by developing internal motivation, which was assumed to come from the resolve of the students to design buildings that would mitigate negative environmental outcomes. In addition, the students were asked to keep a dream diary and did a freewriting exercise. The *secondary* mode was activated by developing external motivation. The students were advised that the best design from the group as ranked by the assessor would be published in the dissertation. In addition, the group was asked to develop shared objectives for the design specifically noting broad objectives in ecological, social and economic areas and to record their progress in their journal.

For the case of *intention* (termed manifestation in the Toolbox), the facilitator asked the participants to establish two specific, quantitative and qualitative targets under the broad objectives in ecological, social and economic areas. This engaged the *reflective* (then termed *rational*) mode. In addition participants were asked to calculate net and gross areas of the designs as an indication of their efficiency. The group carried out a 'fountainhead' analysis of masonry to trace the upstream and downstream environmental impacts of the material. In order to engage the intuitive (then termed *empirical*) mode participants took part in a guided imagery exercise where they were asked to remember significant experiences of 'community'. They took the One Hundred and One questions to the site with them and were asked to take

particular note of their sensory impressions of the site and to record as much information as possible. A landscape architect familiar with the site discussed particular landscape issues such as parameters of tree retention strategies with the students. The students were asked to place their schematic design models on a heliodon (a device which simulates the diurnal and annual movement of the sun) in order to get feedback on solar impact.

### **3.5.2 Results**

The designs produced by both groups of students were assessed by the normal method (professorial evaluation) as well as assessed by an independent assessor using the micro and meso level indicators (Appendix 1). Students were interviewed for feedback on the manipulations and were asked to fill out questionnaires. An independent assessor judged the designs of the control group and the experimental group using the indicators as a guide. The identity of the groups was unknown to the assessor. The work requested of the experimental group and the control group was not completed in all cases. Based on the available information the assessor selected the best design overall and a runner up. Both designs were from the experimental group (the best design is included in Appendix 4).

Based on the results of the pilot project several changes were made to the design of the project delivery and design simulation study. Most significantly, required output was tied to marking to encourage completion of the work by students. A reading log, a design diary, the indicator measures and the design itself became part of the assessment of students for the purposes of assigning marks. The computer program was designed to encourage learning of and practice with the creativity techniques.

The results of the four studies and the conclusions drawn from them are described in Chapters 4 and 5.

## **Chapter 4**

# **Analysis of Research**

## ***A Case of CAS?***

We shall not cease from exploration

And the end of all our exploring

Will be to arrive where we started

And know the place for the first time.

T.S. Eliot

## **4.1 Introduction**

At the conclusion of Chapter 1 I introduced the research questions and in Chapter 3 I described the approach to the research undertaken to address the questions. In this chapter I will describe the results of the research.

The research questions are:

### **Research Question #1:**

*Does a framework for project delivery and design process that uses the processes of complex adaptive systems provide a useful tool for practitioners?*

### **Research Question #2:**

*Does a project delivery and design process that uses the processes of complex adaptive systems result in buildings or designs that are well adapted to their environment?*

**Research Question #3:**

*Does a project delivery and design process that uses the processes of complex adaptive systems result in buildings or designs that are more creative?*

**Research Question #4:**

*Does oscillation between the change and conserving agents and movement between the boundary breaking vehicles lead to creative breakthroughs?*

The principles of the framework were developed in Chapter 2 and are summarized in FIGURE 15. I introduce the terms equilibrium, chaos, development and growth to describe the states in the quadrants of the framework. Equilibrium is a combination of conservation and differentiation. Chaos is a combination of change and differentiation. Growth is a combination of change and integration and development is a combination of integration and conservation. Dynamic equilibrium is attained with balance between the four states and occurs in the centre of the framework.

FIGURE 16 shows the framework in three dimensions and introduces the individual and group aspects of the project process. TABLE 3 shows the specific components of the framework as discussed in Chapter 2.

The independent variables are the control parameters and are shown on the Z-axis: Z1 *cognition* (the change agent is information); Z2 *affect* (the change agent is inspiration) and; Z3 *volition* (the change agent is intention). The moderating variables are the movements between the components of the framework and are shown on the Y-axis: integration/differentiation and change/conservation agents. The process level is shown on the X-axis. Analysis takes place at both the project delivery process level and the group level (X2) and the design process or the individual level (X1). The dependent variable is the adaptiveness (environmental fit) of the design product.

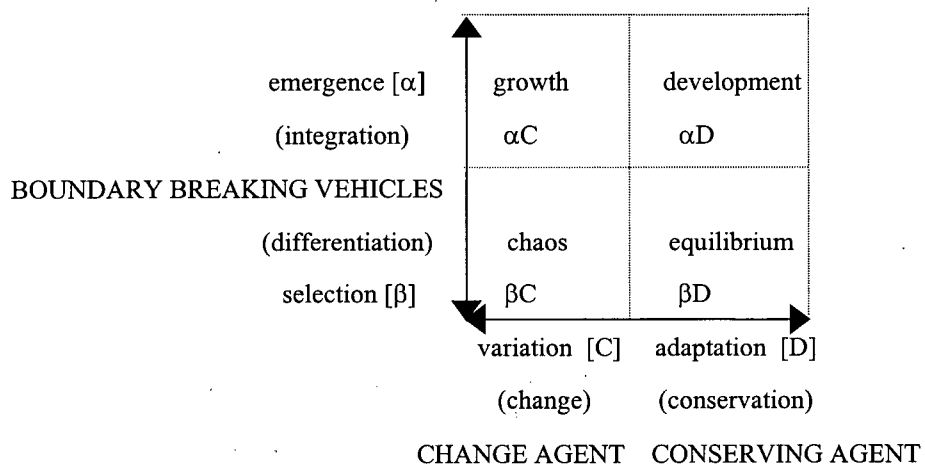


FIGURE 15 THE DESIGN PROCESS FRAMEWORK

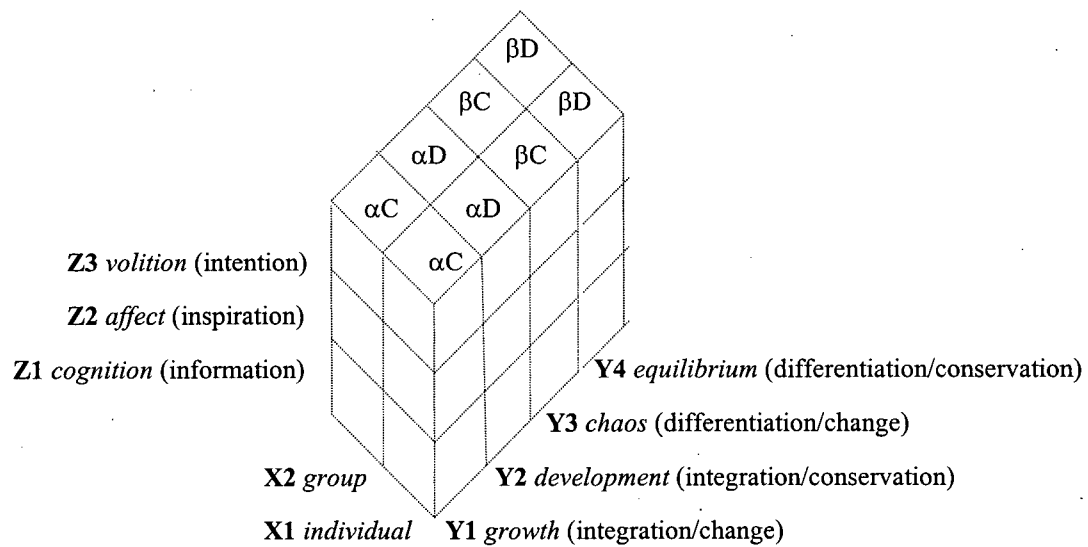


FIGURE 16 THE THREE-DIMENSIONAL DESIGN PROCESS FRAMEWORK

TABLE 3 below summarizes the dimensions of the framework and shows the specific variables:

<b>X dimension</b>	<b>Z dimension</b>	<b>Y dimension</b>	<b>the specific components</b>
group	volition (intention)	growth	intuition/intention
		development	intuition/operation
		chaos	reflection/intention
		equilibrium	reflection/operation
	affect (inspiration)	growth	primary/inspiration
		development	primary/motivation
		chaos	secondary/inspiration
		equilibrium	secondary/motivation
	cognition (information)	growth	synthesis/information
		development	synthesis/knowledge
		chaos	analysis/information
		equilibrium	analysis/knowledge
individual	volition (intention)	growth	intuition/intention
		development	intuition/operation
		chaos	reflection/intention
		equilibrium	reflection/operation
	affect (inspiration)	growth	primary/inspiration
		development	primary/motivation
		chaos	secondary/inspiration
		equilibrium	secondary/motivation
	cognition (information)	growth	synthesis/information
		development	synthesis/knowledge
		chaos	analysis/information
		equilibrium	analysis/knowledge

TABLE 3 THE VARIABLES AND THE FRAMEWORK SPECIFICS

The four research questions will be addressed using the material from the case studies. Not all case studies address all the questions but at least two studies will be used for each question. The think-aloud protocol will not be used in the analysis. That study was intended to be helpful in addressing question number 4 regarding creativity. However, there was no practical way of addressing the degree of creativity of the designs produced. In fact there were very few actual designs produced. Several participants were intimidated by the situation and produced very little concrete work. Others were not very articulate about their activities. No participant recorded a creative breakthrough. Several useful observations can however be drawn from the exercise. It was clear that the practitioners had much more facility in knowing how to go about dealing with the design problem. They would start by laying out the constraints as they perceived them and then explore various ways of tackling the problem through drawing. The process seemed very much to be an internal dialogue of conjecture and testing, thus confirming accepted views of the design

process. The students took different approaches: either getting into one aspect of the problem in great detail or relying very much on standard solutions based on their past experience. A beginning student clearly was floundering about how to start the process. One conclusion is that the design process is a skill that can be learned. Several participants used the concepts from the framework when they were telling me how they had gone about tackling the problem. Here are some quotations that support the framework: "It went from something that seemed like it would be easy to solve to something that was very complicated."; "When I started looking [at the proposed design] straight on I realized that this was right where you want to see where you're going [on the bicycle]."; "I'm looking for something that's going to give me input."; "I'm frustrated that I have no external influences."; "In the end I had that little moment where something just started to trigger."; "You can see I seemed to stick with one idea."; reflecting on having started out with a largely irrelevant detail: "You've got to get yourself there first and once you're there...I guess it depends on the person and how fast you get there."; "The need to synthesize a bunch of things into one...and if I went back and analyzed it may not actually satisfy my personal thing."; "I guess intuitively I was trying to resolve those things."; "What are the constraints?"

The material gained from the Building Case Study, the Seminar in Sustainable Design and the interview with Stephanie Bothwell, a noted landscape architect and professor from the United States, will be drawn on in order to address the four research questions.

Question 1 is fairly straightforward and can be readily assessed using the comments from the practitioners. Question 4 is of interest but the analytical material is not unambiguous and subsequent research would be necessary prior to drawing any conclusions.

The underlying hypothesis of the dissertation is:

*since evolutionary processes have resulted in products that: 'fit' their function; that reciprocate with their environment; that are both elegantly efficient and appropriately redundant; and that further are incredibly beautiful while being both typical and idiosyncratic, then a design process which follows similar processes and which is used by all the participants in the project delivery process will result in products with similar*

*qualities. Further, the processes of complex adaptive systems are themselves 'design' processes and a theory of design process may be developed from them.*

The most central research questions, therefore, are numbers 2 and 3, which address the hypothesis directly. Questions 1 and 4 are related to application of the hypothesis and are secondary. The research seeks to establish whether a design process that learns from the processes of complex adaptive systems will result in more environmentally adaptive and more creative designs. In order to analyze the data I characterize the processes of CAS and use the characteristics as a framework within which to analyze the data derived from the studies. I show how the case studies illuminate the characteristics of project design and delivery when it is considered as a CAS. In answering the research questions I seek to identify causes and their effects in design process in order to illuminate the framework and distinguish features requiring modification or elaboration.

The process of carrying out the dissertation research is very similar to that of doing design. Using the characteristics of CAS that I identify in the next section, I am able to identify my own research process as a CAS. Consequently, it has been edifying to track and use the framework for myself as I have been engaged in the research. In this chapter I shall try to make explicit my own research process and apply it as a heuristic shadow case study. Comments made in this case study will be italicized. As any design process is emergent, so my research process has been emergent and the modifications to my theory that have occurred as a result of the analytical process are made explicit to exemplify the heuristic and emergent nature of the research process.

For example, in the midst of the data analysis for the design diaries, I felt overwhelmed by the amount and diversity of the material I had differentiated. I tried several ways of integrating the material and each time felt that the data needed to be discriminated by different criteria. Finally (and, as many of the groups in the course noted, under the pressure of a deadline) I began to see how the material could be integrated in a useful way and developed the final set of categories of the comments as a series of change and conserving agents which are available for feedback to the framework. Similarly, the first characteristic of CAS identified below is sensitive dependence on initial conditions. In writing up the analysis from the case

studies I perceived that this condition, which I had intuitively felt to be critical, was in fact the lowest level conserving agent in the framework (FIGURE 4, 46). The *kenes* were, I realized, the starting conditions of a project. My first employer said that once a project went 'sour' you could never get it back on track and that has certainly been my experience in thirty years of work on projects. Sensitive dependence on initial conditions means that a small change in the state of a system at time zero produces a later change that grows exponentially with time. It is critical that the early inputs to the 'state' of the project system be carefully considered. Other examples of the emergent phenomena of the research will be made explicit in this chapter.

## 4.2 Analytical Framework

"At the pinnacle of complicated dynamics are processes of biological evolution, or thought processes," Packard said. "Intuitively there seems a clear sense in which these ultimately complicated systems are generating information...created from connections that were not there before." Norm Packard in Gleick's *Chaos: Making a New Science*

While searching for an appropriate analytical framework for the research data, I came across a text on CAS: *Chance and Chaos* by David Ruelle. This text gave a simple framework for a discussion of CAS and provided characteristics that were descriptive of CAS. Using these characteristics provides a simple test for whether a system is a complex adaptive system.

Ruelle (1991, 40, 69, 8, 116) identifies the essential characteristics of CAS as:

1. sensitive dependence on initial conditions
2. different modes of operation giving way to chaos
3. a minimum of three oscillators and interaction between the modes of operation (coupling).
4. complex results coming from simple processes and configurations of systems satisfying the global conditions have a cluster of probabilistic features that uniquely characterize these configurations

5. unpredictable innovation arising morphogenetically through mutually causal interactions and fluctuations

One can readily accept that the above characteristics are descriptions of the design process:

1. the end result (the design or design product) depends very much on the initial conditions: the client's agenda; the project manager's approach and the consultant's skills and experience. The early inputs are critical to the success of the product.
2. the most basic and universally agreed upon description of design is that it involves analysis/synthesis/evaluation as basic processes. The question examined here is whether chaos is a part of the process and if so, whether it leads to discovery or reintegration of existing knowledge. Research question number 4 (*does oscillation between the change and conserving agents and movement between the boundary breaking vehicles lead to creative breakthroughs?*) will be addressed under this characteristic.
3. design involves "the willing suspension of disbelief" and the ability to tolerate the uncertainty of a design in process where the outcome is unknown and is taken on trust to be available - students have likened this experience to being in a dark room full of fog and design teachers to 'knowing that they know but being unable to express what it is they know'. I have identified information (cognition), inspiration (affect) and intention (volition) as energy sources in design and have further identified the modes of coupled interaction as synthesis/analysis, primary process/secondary process and intuition/reflection. Research question number 1 (*does a framework for project delivery and design process that uses the processes of CAS provide a useful tool for practitioners?*) will be addressed under this characteristic.
4. The processes of design are simple and the results are complex products. The global conditions of design are similar for all designers (e.g. available materials, the laws of physics, biophysical systems) but the unique characteristics of designs come from not only the particulars of the site and function but also from the individual characteristics of the designer(s) (Goldschmidt's A and the author's alpha) -

thus some designers will develop an identifiable style which is apparent even in designs which respond to very different constraints. Similarly, it is proposed that when the global conditions are known and understood in a holistic way by designers then the designs will respond more appropriately to those global conditions and will be more sustainable. Research question number 2 (*does a project delivery and design process that uses the processes of CAS result in buildings or designs that are more adaptive to their environment?*) will be addressed under this characteristic.

5. designers will often testify to the unpredictability of 'ideas' - they come mostly unbidden and fully formed - and they do come up with some regularity during the design process, presumably from the interaction of events and/or conditions. Research question number 3 (*does a project delivery and design process that uses the processes of CAS result in buildings or designs that are more creative?*) will be addressed under this characteristic.

Design process displays the characteristics of complex adaptive systems. The central task of the research is to identify the particular characteristics of the design process that illuminate its dynamics as a complex adaptive system. If design process is a complex adaptive system then it will result in products that display adaptive characteristics. Adaptive products should by definition 'fit' their environment. If the design process is broadened to encompass the relevant environmental constraints then the products will be more adaptive and thus more sustainable.

The Pagani framework outlined in Chapter 2 is the grounded theory that is tested in the case studies and further developed as a result. The case studies data analysis focuses on the two central research questions. The analysis seeks to establish causal connections between process dynamics and product results. The analysis takes place at two levels: the individual design process level and the group process or project level. At both levels data is analyzed for CAS dynamics: the control parameters; the change and conservation agents and the boundary breaking vehicles.

### **4.2.1 Sensitive Dependence on Initial Conditions**

A very small cause, which escapes us, determines a considerable effect which we cannot ignore, and we then say that this effect is due to chance. David Ruelle

Sensitive dependence on initial conditions means that a small change in the state of the system at time zero produces a later change that grows exponentially with time. A small event has significant consequences over time. Counterintuitively, many physical systems exhibit sensitive dependence on initial conditions for arbitrary initial condition (Ruelle 1991, 40). That is, it is not necessary for the starting condition to be exceptional for an exceptional result to occur. This could explain why some design products are exceptional when others, which have very similar starting conditions, are unexceptional. Rather than the starting conditions themselves being key it seems to be the early input to the starting conditions that is the critical factor. The same design team will produce a very different quality of design with a different client, a different project manager or the same client but a different project architect or engineer. It is the dynamics of the interaction of the components or the process that is critical to the quality of the outcome.

In the course case study, given the same project brief, the same time allowance and similar resources, the six teams each produced quite different designs and recorded quite different experiences in their journals.

An analysis of the journals shows a convergence of opinion among group members as to group compatibility. A summary of the journal comments is in Appendix 2.9. One group in particular (Halve) seemed compatible and recorded their positive experiences repeatedly: "I have found that the two greatest problems in group projects are those people who lack discipline or energy and those who want to have control over everything. Our group does not suffer from either" and "from the start of this diary I have expressed my thanks for having such an excellent group of professional participants to interact with".

Similarly, one group in particular seemed to be experiencing great difficulty (Full-blown) and the diaries of this group record their frustration: "group is now totally distracted from idea and \_ and \_ removing themselves due to frustration" and "I am frustrated. We are all needing to take a look at the leadership aspects of the design process". An analysis of the results of the consensual assessment compared to the journal contents shows that the designs judged most sustainable were generally produced by groups which

recorded a productive and co-operative process and vice versa. Judged by consensual assessment, the Halve group's pre and posttest designs are first and third out of twelve and the Blood group's are second and ninth. The Stoneware group's designs are third, equal to the Halve group, and fifth. Gram Molecule's are seventh and eighth. Atlas Mountain's are sixth and tenth and Full-blown are last at eleventh and twelfth. A count of positive and negative comments from the journals concerning the group process shows Halve with no negative and 18% positive (out of 95 comments on process). Blood has 3% negative and 3% positive out of 77 comments. Stoneware has 22% negative and 5% positive out of 63. Gram Molecule has 4% negative and 8% positive out of 25. Atlas Mountains has 14% negative and 8% positive out of 50 and Full-blown has 31% negative and 5% positive out of 65. It appears that generally the groups that worked well together and felt positive about the experience also produced the best work.

In accounting for this observation, it will help to identify the key variables in the group dynamics. Since the groups were similar in composition; that is, with student/professional mix and with discipline mix, this factor can be ruled out. Hare (1992) lists different system levels that are necessary in social psychology to explain behaviour: individual biology, personality, group, organization, social system, culture, and environment. Speculation about the critical factors in this case would be restricted to individual biology and personality. Organization, social system, culture and environment are fairly consistent among groups. All the group members worked under the same organizational constraints (the course), they operated in similar social systems and from within the culture of design and they worked in the same environment for the duration of the course. It seems fairly conclusive then that the personality of the group members was the key variable in the group dynamics. A member of the Halve group said, "the bonus is that our personalities are all quite co-operative and open-minded and no-one seems to have ego excess". Since the focus of the study was not on personality as a variable I have not analyzed the group dynamics based on personality.

Additionally, the requirement to set three targets for the second design, was commented on favourably by some: "All the discussions we had were always in the light of the three targets we set...and it was very helpful to follow them because it made me think in a very orderly and efficient way"; and commenting on

designing in a group “[different from] an individual project creating, this situation made me more specific in my priorities”; “we discussed our objectives: which turned into a one hour long discussion about what we each feel is of critical importance to our design”; “wonderful idea - Three goals - targets evoke a very good discussion. Helped us to focus on important issues”.

The conclusion I draw from the above is that the early input to the starting conditions is critical to the outcome of the design process. It is here that a project initiator should exert most energy. Establishing suitable starting conditions and input will give the most significant results for the outcome. The process starting conditions include: consulting team composition, owner approach, management approach and the development of common goals.

The Building Case Study illustrates this principle. The success of the project is in part traceable to the starting conditions: the owner had set an agenda for a demonstration green building; the project manager was supportive of the agenda; all the consultants were motivated to work on a green building (the architects were selected in part based on their interest in green buildings and as prime consultant they selected their subconsultants based on interviews to determine their interest/expertise in this area) and; the start-up workshop facilitator as well as an invited professor had expertise in green buildings and were able to provide examples of precedents. The objectives for the project were established at the start-up workshop. Another project under the author’s control had a similar workshop after the project team was in place and had started designing. The end result was much less successful in terms of the criteria of meeting the environmental objectives established at the workshop. Other agendas had moved to the forefront in decision-making and it was not possible to ‘turn back the clock’; time is irreversible.

#### ***4.2.2 Different Modes of Operation Giving Way to Chaos***

Because I’m used to the fact that you have to go through chaos in order to create anything, I’ve decided to be really calm and realize that there’s going to be some chaos while we figure out what the next thing is.

James Kudelka

This characteristic addresses research question number 4: *Does oscillation between the change and conserving agents and movement between the boundary-breaking vehicles lead to creative breakthroughs?*

To introduce the basic notion of chaos, Ruelle quotes Poincare on unpredictability "A very small cause, which escapes us, determines a considerable effect which we cannot ignore, and then we say that this effect is due to chance" (ibid., 48). A more formal definition of chaos is: stochastic behaviour occurring in a deterministic system. Stochastic behaviour is intrinsically unpredictable (Clayton & Radcliffe 1996, 24). A lay person's definition of chaos would probably be lack of order.

Ruelle states that there are presently only vague criteria for the presence of chaos in a system. Chaos used in terms of systems describes processes that are not actually random but look random. He defines a mode as a periodic motion. With the application of an external power source, more and more modes of a system are excited (ibid., 54). If several of the modes of operation in the system are oscillating independently, then the motion of the system is not chaotic. However if the modes are coupled or interacting, then the evolution of a mode is determined not only by its own state but also by the states of the other modes. In order for chaos to develop and for sensitive dependence on initial conditions to occur at least three oscillators (or modes) are necessary. Furthermore, introducing interactions between independent systems makes the occurrence of chaos more likely especially when the coupling is strong (but not very strong). Although a system may exhibit sensitive dependence on initial conditions, this does not mean that everything about it is unpredictable. "In fact, finding what is predictable in a background of chaos is a deep and important problem" (ibid., 81).

In terms of the framework, my assumption is that creative breakthroughs arise out of chaos, which comes out of the combination of differentiation and change. The chaos is the state of uncertainty that comes from having a mass of differentiated information and a question/concern arising as to its relevance to an existing frame of reference. The question will arise as a result of the change agent's influence. The ensuing 'chaos' arouses the individual or group to strive to integrate the information into the existing frame of reference or even to develop a new frame of reference. The first type of integration is accompanied by a more minor sense of 'click' than the second type, which is rarer and can be perceived as a breakthrough.

One student in the course said about the model of the design process “[t]he idea of framing the mind to such a defined process is I think in opposition to the creative thinking process where chaos is often in action”. Although he had misunderstood the intent of the model, his description of the design process as being chaotic is interesting. While analyzing the 375 extracted diary comments my own state of mind could also have been described as chaotic. I was ‘drowning in detail’ with no organizing framework. When I started to become familiar enough with the content of the comments I began to see ways of imposing order on the chaos and integrating the information that was coming out of the chaos into the information set that I held up to that point. As the integration occurred the original information was transformed. This is when ‘clicks’ occurred. This confirms the idea that design involves different modes of operation giving way to chaos.

In the interview Stephanie Bothwell mused about her non-linear design process: “some designers describe their process as linear...we go through a series of steps and although it may look like there’s a kind of confirmation or inevitability, I don’t find that’s true at all about my design process. I call myself a hunter/gatherer and whatever resource there is, I consider it my job to catch...like a resource, whatever resource there is...and I slowly gather it and intensify it, not sure where it’s going when it’s happening. The moment at which you do the most letting go, the most ‘aha’s’ and the most ‘stuff’ happens...but it’s not without activity. It’s...umm...hunting and gathering and looking...it’s partly the serendipity of silliness... And then there’s a moment...and then usually something happens...there’s a ‘click’ or a crisis and then the collective intelligence of the thing itself...you just...there’s a moment when you go on instinct ...instinct comes in at some moment or responsiveness...gut...you just say “you gotta have some of this, but you don’t have to have some of that”...there is a moment of truth. Like the Shakespearean...what is it?...you have to screw your courage to the sticking point. The sticking point is always when you’re drawing the master plan and as you’re working your way inch by inch across the plan then you have to make a decision...you have 30 seconds...well, I think the whole reason we spend all the time...we spend all the time in the talking is that you’re looking at a certain sense of resolve and excitement...you’re trying to find, or score, something and we avoid the paper for a lot of reasons probably some of them good and some of them bad...there is a moment of truth and it takes courage to commit. It’s finding the courage...it’s

finding courage just to say O.K. now and sometime that comes with a little bit of fear but it also comes with feeling that something is driving you...something that gives you passion...there is a message that it's important to get across and once you have that, the task, which is really awesome and odious, seems really small."

Later, she brought chaos into the picture "how one little system not quite linking...it doesn't take much to cause chaos. There's a perception of chaos and how something can ameliorate chaos or bring order...you know when you look at the plans yesterday and how that brings a kind of order...how what appears to be a set of random acts...a kind of chaos thing you're trying to get control over at the same time trying to increase chaos within the natural systems instead of trying to neutralize it."

In the seminar questionnaires several respondents note 'clicks'. "A member of our group thought of how applicable a monastery would be...she made that discovery while doodling as she listened to our guest speakers." Perhaps the doodling was supplying new (random) information that prompted the insight that the monastery layout solved many of the layout problems that were at issue (the doodling was a change agent which prompted integration into a holistic concept out of the chaos that came from analyzing the project brief and constraints). Another describes the steps leading up to a decision where the main entrance "fell into place within seconds rather than minutes. It is hard to explain the lead up to this moment. On paper it sounds boring but the experience of this act of mutual agreement was equivalent to plugging in the Christmas Tree lights after fussing and shuffling ornaments for two hours. At this moment I could picture our building inside and out." One student described the design process as "metamorphosis sort of like flash cards". Another says "a second insight came as we were stuck in the first idea...how to create one building from this...then came [the] idea to create one roof to cover" and in relation to the same issue, another says: "the group spent approximately 45 minutes trying to define what 'university within a university' meant to them, to try to solve the design problem." Here again is this sense that the differentiation of the information is a key step prior to the insight occurring.

So a cautious answer in the affirmative to question number 4 seems plausible. While the sense of oscillation was not made very explicit, it does seem that, at the very least, 'clicks' come from a pressing

need to make sense out of an array of information that has been gathered and sifted in relation to the problem that is under consideration.

### **4.2.3 The Oscillators and Coupling**

Research question number 1: *Does a framework for project delivery and design process that uses the processes of complex adaptive systems provide a useful tool for practitioners?*, will be addressed under this characteristic of CAS.

In my framework, cognition, affect and volition are the sources of energy that excite the modes. The modes are growth (Y1), development (Y2), chaos (Y3) and equilibrium (Y4). In design, I propose that, when increasing differentiation is coupled with a conserving agent the result is equilibrium (or stagnation); i.e., as information is separated and analyzed, as feelings are dissected, or as goals are debated, then the result is a state of equilibrium or stasis. In the seminar design diary one student, after the Blood group posttest design, writes of the frustration of lengthy discussions about whether the pretest design should be revised or a new design undertaken: "frustration, the group can not [sic] get into agreement...we all feel very confused". Later he says, "we are still in the same spot" and still later, "we are still in the same point". At the next session the group cannot come to a decision and he says, "decided to mull over these ideas and decide on our approach next class. We get into the tight corner." As a way of getting out of the situation the suggestion is made that "each of us is suppose[d] to bring a picture 'that strike[s] us in some way' and using this picture we will try to move from the dead spot." Writers refer to this state as having writer's block and designers talk about being 'stuck'. In architectural practice, increasing regulation promotes this state. The options seem to narrow down to the point where no action is possible within the existing parameters.

Either bringing in a change agent (as the students proposed with their pictures) or increasing the degree of integration will move the designer to another mode. However, if there is then increasing differentiation along with a change agent, the result is chaos. As the designer seeks to make sense of the chaos, integration (Stephanie's desire to bring order) again increases and chaos gives way to a new level of dynamic equilibrium. Stephanie says categorically that it is instinct that operates at what she calls 'the

moment of truth'. I have called this integrative mode intuition. The other modes that I have identified are synthesis and primary process. It is primary process that is being sought when it is suggested that the Blood group bring "pictures that strike us in some way". Synthesis is in operation in the group work when consensus is reached - members are able to accept a point of view or position and integrate it into their own point of view. One student says, "it felt like we were finally getting somewhere by almost subconsciously combining several ideas from all of us into one - amalgamating". One group split into two to develop initial ideas and this "...was a success. The team felt in control and the decision process was fast and without major problems". But when they came to synthesize the two groups' work, "there was no consensus within the team". When the information that is shared by the group is accepted as a common framework the integration is easier: "the same ideas of interconnectedness and the need for interaction jumped out at the whole group - a relief for me because we're all on the same track". Another group was happy when one member "suddenly came with a form that seemed right and all the pieces fall into place". But with reflection (differentiation) the synthesis turned out not to be so right: "however as we continued to look at the details, more arguments arose. It seems that this concept was strong verbally but hard to implement". One group noted that the fact that the group work had a profound effect on the final product: "I could notice that even though I had a general concept...the actual form was created by sequence of reaction to the other idea [sic]. Meaning that...the outcome of this project done by individual members would have been difficult and more extreme". This description of the difference between the outcome from an individual and from a group is a good example of the added complexity introduced by the group interaction. While this complexity can be destructive in groups where the starting conditions are not positive, it can also produce results that would be inconceivable with an individual designer; more innovative or more complex or more considered. A landscape student says, "I am used to working in groups of landscape architects only which is unbalanced and generally favours idealization over pragmatism." For these students the group interaction has a modifying effect which favours a more realistic and rounded (more complex?) design. Of course the constant criticism and feedback (differentiation) that comes from the group members is also frustrating to those who are used to autocratic decision making. "I can recognize that I can learn a lot from \_ and \_, and yet \_ is also getting frustrated

with the design process...4 different people and 4 different ideas.” One group solved the integration issue by devolving the role to an individual: “because of the very democratic way of the design process in regards to the generation of ideas, every team member put his/her input in the design. The selecting process was a little more difficult and one team member had to take decisions.” Other groups weren’t able to solve the integration issue at all. “The frustration of group design is definitely apparent in our group.” One architecture student made a “...suggestion that the main decisions after a group consideration should be left for the architects” and noted “...even though architecture was not the major of some people it seems that everyone has so much to say about it.” Others recognized the value of the interdisciplinary input: “...all participated in each decision. Although this was time consuming I found it extremely valuable because of the diversity of our backgrounds. People with planning and landscape architecture backgrounds offer novel insights to design problems”.

In the questionnaire distributed after the posttest, the trial group was asked if the model represented aspects of their design process. Seven out of seven participants said yes and rated the degree of closeness as 26 out of a maximum of 35 points using a score equal to the value of the graded scale for responses (i.e., 1 - 5). So it seems that designers can readily relate to the description of creativity in the model.

The project process has a starting condition that consists of the project parameters. The control parameters (information, inspiration and intention) are like the power applied to turn a tap to control the water flowing from it. The opening at the tap regulates the power applied to the fluid (which is gravity). A small opening results in a steady stream, a slightly bigger opening results in a pulsating motion called periodic and a larger still opening results in irregular flow until with a wide open tap the stream becomes turbulent. This succession of events is typical for fluids excited by a progressively greater external power source. More and more *modes* of the system are excited. A mode is a periodic motion. If no modes in a system are excited then the system is steady state; if a single mode is excited there are periodic oscillations; if several modes are excited the flow becomes irregular; and when many modes are excited it becomes turbulent. Ruelle suggests that there is a continuum of frequencies and that the time evolutions of dynamic systems are much richer and more interesting than this simple model from physics (Ruelle 1991, 54).

*As I wrote the sentence on modes, the information contained in it suddenly made sense to me in relation to a puzzle in the data analysis of the diaries. I was surprised that the greatest number of references from the diaries went into a category I called energy/emotion. It occurs to me now that emotion may be the external power source that excites the 'modes'. I have just experienced a 'click' that came about as a result of integrating some anomalous knowledge I had previously noted and left aside. The new context came from thinking about the general theory and this allowed me to 'propose' to myself a possible integration that now needs reflection and criticism before being accepted. I want the framework to reflect the theory and the practice. After I wrote this I went back to finish the sentence in the main text that had triggered it. The very next sentence I wrote triggered a further 'click' which related to another puzzle I had left from the data analysis. It seemed that information could act both to inspire and to form intention. I had difficulty categorizing several of the diary comments until I had made this observation. I again left these apparent contradictions to one side for later consideration. A third 'click' occurred when I wrote 'modes are excited' - this was a confirmation of the first click I had just had - the word 'excited' (which is taken from physics) applies beautifully to the human emotion during design. Examples from the diaries are: "I am very excited by the possibilities", "we are excited about our use of water", "the team is enthusiastic", "everyone seems quite pleased" and, several times, "a feeling of accomplishment", "not a real hotbed of creative energy tonight", "exhausted", "disappointed", "low energy" and often "frustrated". This insight represents a new view of the framework. It occurs to me that perhaps I am in a turbulent state right now - I certainly feel very 'excited'!). I have found an instance in my own process of information moving me up through to intention and the intense feeling of excitement I noted that accompanied the process was either a 'cause' or an 'effect'. "When many modes are excited it becomes turbulent"!*

Stephanie Bothwell says of working on a design charrette in an industrial suburban area of Vancouver that "there's no juice to draw on. It's really sad. You're looking for some authenticity somewhere...I also think the moment of 'aha' happens at the point at which you get mad...you get pissed off...the emotion of that drives you to say this isn't what's meant to be...let's find something better." This emotion is the inspiration component of the model. The excitement that is referenced in the design diaries is I believe something slightly different than the emotion. It is related to the feeling of being on the track of something

important. The dictionary definition of excite is *to stimulate the emotions of*, and in physics is: *to raise a system to a higher energy level*. Excitement is both a cause and an effect. It comes about as a result of new information and can produce emotions/inspiration and intention.

*It is interesting that Stephanie uses the word "drive". That is exactly the sense of excitement that I describe above - it drives the process. Again this is new information in relation to the model. I need to 'fit' it into the model. After some reflection on excitement and what it means to me personally, I believe that it may be a change agent. There wouldn't be nearly as many babies in the world if sex weren't exciting. Actually, although sex is exciting, to be more exact, it is the excitement that comes from arousal that drives the completion of the sex act. Excitement requires some sense of accomplishment or completion or it leads to (AHA!) frustration - the most used word in the diaries. In the dictionary, frustration is to keep from doing or achieving. This is related to the volition (striving) parameter. So perhaps excitement is the change agent that works in volition. In Figure 3 I identified intention as the change agent and operation as the conserving agent at the volition level. Setting a goal is often accompanied by a sense of excitement but is it brought about through excitement? I don't think so - it's more that it's brought about through frustration or the need to achieve the goal that has been set. (On reflection: it seems more that excitement in design or research is the feeling that you're onto something - it could be driven by intuition.) Perhaps drive is the best sense because it includes excitement and frustration and comes about as a result of intention. Is drive common to all three parameters? Do the other change agents (information and inspiration) come about under the pressure of drive? Yes, I think so, frustration and excitement will spur one to seek new information or to generate alternative solutions to a problem. So perhaps they are simply the energy that activates the change agents and conserving agents.*

Unlike the hard sciences, in the 'soft' sciences there are no basic equations of motion and the dynamics of the system are not usually simple. Furthermore, Ruelle (ibid., 79) points out that, "in many cases including ecology, economics and social sciences the basic equations of evolution, whatever they are, slowly change with time (the system 'learns')". So, quantifying any of these dimensions in social systems is just not possible at present. Analysis of these problems will be somewhat fuzzy and all we can do is collate

qualitative evidence while remembering that, "Poincare's considerations on predictability in meteorology were just scientific philosophy, and this domain is now quantitative science" (ibid., 79).

In Ruelle's terms my framework is "an idealized time evolution" of the project design system. In order to determine if a system is chaotic, at least three oscillators are necessary. Coupling produces chaos. Furthermore, introducing interactions between independent systems makes the occurrence of chaos more likely "...especially when the coupling is strong (it should not be very strong)". Ruelle also points out that only moderately complex systems exhibit the tendency to return to close to where they were earlier. The evolution of very complex systems is one way: history does not repeat itself, at least in detail. In design, every project is unique but some projects are more predictable in terms of their outcome than others. One can say that the design process of these projects will be less complex than one in which the outcome is less predictable. One definition of a complex entity is that it embodies information that is hard to get. The least complex type of time evolution is steady state where there is no time evolution. The next simplest type of time evolution is periodic oscillations (for example, fashions), then comes the superposition of two or more oscillations, then chaos. I have already observed that one student believes that "chaos is often in action" during the creative process.

*I am reviewing the notion of 'clicks' and how they fit into this schema of modes of operation. It seems clicks come about after a train of thought is followed and it is suddenly seen to 'fit' (that adaptive word again!) into a previously held construction of thought. The 'click' occurs as the 'fit' is perceived. Is the 'click' simply the sign of a new level of integration in a mode or does it also signal a shift to a different mode? It seems not to be a shift to a new mode. The 'click' seems much closer to the lifting action described in the Jantsch diagram where the curve moves down into chaos and then pushes up to the level of the new dissipative structure. (Later: this sounds like Daniel Dennett's concept of cranes.) In thought this seems to be a new level of integration of knowledge/information. AHA! Information. The control parameter seems to be the 'bootstrapper' to new levels of? In the questionnaire, five students out of eight noted that they had experienced clicks. In Stephanie's interview she experienced two 'clicks' while talking to me. I also experienced 'clicks' recently while being interviewed by a student for a project. It seems to*

*be the force of the pressure to respond to the interviewer that brings about the reintegration. I have experienced this also when lecturing. Under the pressure of the moment a new thought will occur. This seems to happen spontaneously. Note to myself: different pressures that may bring about 'clicks' need to be identified. So far they seem to be time, frustration/excitement, and situation (e.g. lecturing, being interviewed). These are all constraints that silence the conserving agents and force a reintegration. The boost from a pressure that results in a click!*

In the course, I introduced a *shock* to the design system, in the form of the manipulation of the information variable, when I asked the groups to incorporate their names into the design. Some groups absorbed this shock after a short period of chaos and others found it very difficult to overcome at all. The Blood group produced a very creditable pretest design (judged second for sustainability in the overall rankings according to the consensual assessment) and then spent two thirds of the time for the posttest design 'stuck' - discussing whether to abandon or modify the first design. Naturally, there was no time left to carry out a creditable design for the posttest condition. This shock was so great that the system (the group) never completely recovered. On the other hand, the group admitted, "it made a lot of ideas come up - doors as valves". A member of the Blood group said of the intention manipulation (the establishment of three goals): "Wonderful idea - three goals - targets evoke a very good discussion. Helped us to focus on important issues." However, it seems that the intention was unable to overcome the obstacle of the equilibrium brought about by the lengthy debate on changing the design.

Ruelle describes the process of thinking about science and it sounds very much like design. "If an interesting possibility seems to appear, it has to be brought into focus, verified, sometimes retained but mostly rejected. Bold general ideas have to be developed, but details must then be checked, and all too often, disastrous flaws are discovered. The construction must be rearranged or large parts of it discarded." (ibid., 103)

Coupling seems to occur in design as new data is obtained and integrated or discarded through the use of the boundary breaking vehicles. The data becomes information when it is integrated into the knowledge system of an individual. Some information then stays on the level of simply information. Other

information seems to be inspirational and both information and inspiration can be at times intentional. One student says in the diary: "I try to receive the objective information, maps and program...we went to the site itself to have the second level of emotional sensory information...now I had to look again in the informative material especially in the map. Some information that was meaningless at the time became useful now". This is *information as information*. Another says "I felt loaded with all the new information and ideas from the reader and I felt I truly wanted to give it a try" and another says " \_ brought up the wonderful idea of a monastery" and yet another "we all agreed to go and look at FORINTEK and FERIC [UBC buildings] as sources of information and inspiration". This is *information as inspiration*. The comments "enforcement by new ideas implementing the name of our group into the design" and "our design was guided from the beginning by issues that would be associated with landscape or planning traditionally" are evidence of *information as intention*. This is an example of how the broader issues that are relevant to sustainable design can be incorporated into the project delivery process. Bringing those points of view to the beginning stages of a design impacts the design product significantly in terms of sustainability. The context for the designer is broadened.

Finally "now that we have been further inspired [by the Director] we are more concerned about the quality of experience the institute will have to offer" shows inspiration as intention. In the interview Stephanie says of her work with communities: "the force and intelligence of their vision gives me enormous power". Stephanie is saying that as she gets to know communities "really seeing what's there" and becoming "sensitive and responsive in how to mutate the basic stuff" and "transforming factual knowledge by experiential knowledge" she draws on the intention of the communities for inspiration.

*As I wrote this I realized that I had been searching for inspiration as intention in Stephanie's comments. What I found (after differentiation) was actually inspiration from intention - a new thought - this implies a backward direction in the framework as well as a forwards direction. Something to reflect on!*

So it seems that coupling of the parameters occurs quite naturally.

From the observations that came from analyzing the seminar data and the interview, it seems that many of the aspects of the framework are present in a lively way during design. While it appears that the

framework is realistic in its interpretation of project delivery and design, it is not necessarily the case that it is useful. Research question number 1: *Does a framework for project delivery and design process that uses the processes of CAS provide a useful tool for practitioners?* was addressed directly in the questionnaire with the posttest trial group who were the only participants exposed to it. Out of a total of eight possible responses, five said they had experienced ‘clicks’ when designing and of those, three of the respondents felt that use of the model helped them experience ‘clicks’ and two felt that it did not. Using the response scale to assign values from 1 - 5, the value of the model of the design process was scored at 20 out of a maximum of 40. All seven respondents said that they felt the model would be more useful if it were simplified and two felt that more time was needed in order to understand it. One mentioned that the terminology could be simplified and gave the example of varying/selecting. I have now changed these terms to change agent and conserving agent.

It seems from these results that, while the framework is assessed to be representative of the design process in its present form, it is not very helpful to designers when they are designing. In its present form it is descriptive and predictive but needs more elaboration as to the conditions under which it is predictive in order for it to serve as a practical aid to experienced designers. It seems likely that the framework itself will be more useful as a tool for design educators and researchers. It may serve as a reference point for pedagogy in the design studio.

#### **4.2.4 Simple Processes and Complex Results**

“If one imposes a simple global condition on a complicated system, then the configurations satisfying this condition usually have a cluster of probabilistic features that uniquely characterizes these configurations. Read the above sentence again: it is deliberately vague and metaphysical, so it that it could be applied to painting or music. Authorship by a certain artist is then the “simple global condition,” and the “cluster of probabilistic features” allows us to identify the artist.” (ibid., 116)

This characteristic is related to research question number 2: *does a project delivery and design process that uses the processes of complex adaptive systems result in buildings that are more adaptive to their environment?*

The adaptiveness of the buildings to their environment was measured in two ways: by the students using the indicators and by the experts in the consensual assessment session. The indicators are a tool for relative assessment. No attempt was made to weight the various categories. It was felt that this was not necessary since the adaptiveness of the designs relative to each other was being assessed. All the students in the seminar used the indicator sheet (see Appendix 2.4) to mark each design out of 10 in each category. The designs were viewed in a mixed random order and the pre and posttest designs were anonymous. The results were as follows:

			Economic Micro (max 480)	Social Micro (max 720)	Social Meso (max 420)	Ecological Micro (max 300)	Ecological Meso (max 540)	Total (maximum 2460)	Rank Order (Indicators)	Rank Order (Consensual Assessment: Sustainability)
Trial	Full-Blown	Pretest	219	437	237	138	237	1268	12	12
		Posttest	314	556	331	214	362	1777	3	11
	Atlas Mountains	Pretest	251	429	266	175	321	1442	10	10
		Posttest	326	503	288	199	358	1674	6	6
	Stoneware	Pretest	333	505	271	207	359	1675	5	5
		Posttest	255	514	233	121	308	1431	11	3
Control	Halve	Pretest	273	490	260	172	313	1508	9	3
		Posttest	347	598	329	223	424	1921	1	1
	Gram Molecules	Pretest	306	516	285	187	400	1694	4	8
		Posttest	286	542	294	136	378	1636	8	7
	Blood	Pretest	291	515	262	209	397	1674	6	2
		Posttest	334	576	344	204	404	1862	2	9

TABLE 4 THE STUDENT ASSESSMENT USING THE INDICATORS (shading indicates a higher score from pretest to posttest)

Four of the six groups improved their scores from the indicator assessment from the pretest to the posttest design. It can be seen from the table above that the two groups that did not improve only showed slight reductions. One group (Gram Molecules) was .03% less and the other (Stoneware) was 14% less. The

Stoneware group decided to split the program into two buildings in the posttest design. This major change (presumably for social sustainability) was probably influential in the assessment as being less ecologically sustainable. In the consensual assessment exercise, five out of the six groups improved their assessment from pretest to posttest and one (Blood) was significantly worse (a decrease of 34%). The Blood group were unable to conclude in a timely way about whether to do a second design or not and consequently had very little time to actually produce a second design.

			Sustainability	Technical Competence	Creativeness	Aesthetics
Trial	Full-Blown	Pretest	12	12	11	12
		Posttest	11	8	4	6
	Atlas Mountains	Pretest	10	10	9	8
		Posttest	6	5	3	3
	Stoneware	Pretest	4	4	12	11
		Posttest	3	1	5	7
Control	Halve	Pretest	4	6	10	9
		Posttest	1	3	8	10
	Gram Molecules	Pretest	8	11	7	4
		Posttest	7	8	6	5
	Blood	Pretest	2	2	1	1
		Posttest	9	7	2	2

TABLE 5 THE CONSENSUAL ASSESSMENT FOR SUSTAINABILITY (by rank order - 1 is high)

Overall, the assessment by the indicators and by consensual assessment agreed exactly or within one place in six out of twelve cases. Also, the first and last ranked were the same in both cases. These results give some validity to the two assessments.

While not by any means conclusive, the results are above the statistical norm and are encouraging. It seems then that the framework was of some value in increasing the adaptiveness of the designs.

In the case study, if one looks at the process of developing building B as a system, the key simple global condition that was imposed was the instruction to the project team to make the building a demonstration of environmentally responsible design. The cluster of probabilistic features that satisfies this condition is the

collaborative project delivery process. Several other buildings on the campus were given similar instructions i.e., the same simple global condition and the cluster of probabilistic features was apparent but different enough to affect the end product in some degree. Of the four buildings started after building B only one other is, in the author's opinion, potentially as least as innovative. The first (and most innovative) building was designed but not constructed so its innovative features have not been tested. The second of the four buildings changed substantially in program and location and has not yet been designed. The third was managed by a project manager who was totally opposed to any non-standard features in the building (lack of intention). The fourth was fast-tracked and although the project manager and the project architect were keen to be innovative, the partner-in-charge of the firm was less committed (lack of inspiration). Pragmatically, for a fast-track project standard proposals lead to faster approvals. All five design teams attempted to incorporate environmentally responsible features into their designs. However, particular project parameters affected the process negatively to greater or lesser degrees.

In order to elicit feedback on the case study project from the project team, a post construction debriefing was held. All the major participants (owner's representative, users representative, architects, engineers, landscape architects and contractors) took part. Each individual was asked to give the three aspects of the project that they believed were particularly successful and the three that were the least successful. Listed below are all the responses along with the role of the respondent and the number of times the statement appears. While the comments do not necessarily represent objective truth, they are interpreted as being indicative of the team members' perception of the differences between the subject project process and other project processes that the team members have experienced.

1. team concept (including users as well as subconsultants)	architect, landscape architect, 2 mechanical engineers, project manager, electrical engineer	6
2. sufficient time given to team for design & contractor to construct	architect, landscape architect, contractor	3
3. information about sustainability	architect, landscape architect, contractor	3
4. motivation by client/specific objectives set	architect, mechanical engineer, electrical engineer	3
5. ability to secure materials ahead of construction contract	structural engineer	1
6. inventory of used materials available	structural engineer, contractor	1
7. trade-offs could be made between ecological objectives and cost (economic) and safety (social)	structural engineer	1
8. idea of demonstration of sustainable principles e.g. greywater system, rainwater retention, natural ventilation	mechanical engineer	1
9. personal commitment promoted perseverance in implementing more difficult design strategies & champions came forward when needed	2 mechanical engineers contractor	3
10. on-site recycling in construction was a profit maker	contractor	1
11. amount of publicity received	mechanical engineer	1

TABLE 6 THE C. K. CHOI CASE STUDY DEBRIEFING COMMENTS

It can be readily seen from TABLE 6 that the team approach (number 1) was seen as the most critical ingredient for the project. One can speculate on several reasons for the importance of the team approach. First, most of the subconsultant work on building projects is usually carried out after the architect has finalized a design concept. This means that the expertise of the subconsultant is confined to applying standard design strategies to a fairly fixed concept. In cases where the team approach is used, these consultants are encouraged to give formative input to the design concept. Not only does this make their job more interesting by allowing them to problem solve productively, but it also gives them the satisfaction of having a more constructive role in the project development. More importantly, it allows the overall design strategies of the architects to be informed by the constraints of the specialist discipline. Thus, the form of the building can be designed to accommodate the requirements for the building systems in a much more integral way than normal. For example, in Building B the roof form is predicated on: cultural symbolism; social symbolism; intensifying natural ventilation stack effect flows; allowing north daylighting; and orientation for photovoltaic cell retrofit. Although the architect developed the final form,

the structural, mechanical and electrical engineers were involved in its development. This multivariate response of a form to its environment is a key aspect of natural forms.

The input of the team members throughout the design (and construction) process can be summarized as an efficient way to acquire and share *information*. Further it is a vehicle for developing and maintaining shared *inspiration*. It can also be thought of as an important mechanism for the development and achievement of shared *intentions*.

After the six votes for teamwork, there are four categories with three votes each. The remaining categories each received one vote and are items of specific interest to a particular discipline. The four categories with three votes are: the provision of *information* on sustainable design (which came from the facilitator and an expert in the field who attended the workshop and which inspired further research on the part of the team); the provision by the owner of sufficient time for the team to design and construct the building (allowing a considered response to the project constraints - this slow evolution of a form in response to its environment is also an adaptive strategy in natural form); the motivation prompted by the owner by the setting of specific objectives (*intentions*) at the outset of the project; and the internal motivation (*inspiration*) that was present in almost all the members of the team. Anecdotally, I was told by a couple of team members that this internal motivation was present before the workshop in a general sense but that the workshop had crystallized it into a commitment.

The significant aspects of the project that the team felt were least successful were: more project participants should have been involved in the initial workshop (e.g. the building inspectors, campus community representatives, the quantity surveyor and the specification writer); the standard fee schedule did not cover the additional work that was required of the consultants to do the project justice; the consultants should have had a role in monitoring at least the first year of operation; the cost reductions required after the tender price came in too high meant that some features had to be deleted.

A few selected quotes from the session are revealing of the degree of passion felt by the team about the project:

- We were a “real team”.
- The objectives “drove us”.
- The project “took on a life of it’s own”.
- The client commitment made us “ready to do something different”.
- The project was “not an easy but a constructive and positive education”.
- “The fact that the goals set out target values was very, very important.”
- “The focus on goals made the project a success.”
- “The users are very, very happy.”

So in terms of simple processes giving rise to complex results, it seems clear that some fairly minor changes to the project process can give rise to significant results in the product.

People base their identification of a system on statistical evidence. Probably, a man is taller than a women, has shorter hair and a deeper voice. Every now and then the evidence we use in identifying gender will turn out to fool us but most of the time it works. On the other hand, why is a signature so hard to copy convincingly? Signatures are all made from cursive writing and a combination of 26 letters. But the unique development of a particular individual guarantees particular differences that make each signature distinct. These paradoxes are the cornerstone of equilibrium statistical mechanics (ibid., 116). Our brains allow us to perceive both the cluster of probabilistic features and the unique differences that make the human world so interesting.

In the interview Stephanie talks movingly about the human condition at the present time and just as movingly subsequently about the particular circumstances of the place (Vancouver) where she has just completed a design. When asked if there was a particular moment when she made up her mind to practice sustainable design she talks about working with inner city women in Boston to make community gardens and her realization that the people there were trapped in their situation: “it’s more that people have to get control of their lives...to me I think it was this issue, this justice crisis and also a realization that I couldn’t

deny my responsibility. Sustainability's about taking responsibility...the idea that the community or culture must be maintained...the permaculture...and that culture is maintained and partly preserved through form."

Later, describing a walk in the rain the day before she notes how the rain in Vancouver is different than other places she has experienced "how incredibly gentle it is...it's almost gone before it hits you...and the light's very particular...I felt surreal...I felt floating". For her, both the global issues of justice and the local particularity of Vancouver rain are equally important in approaching the possibility of a sustainable as well as a beautiful and just community for Burnaby.

*Now that I've written this, how does it 'fit' the framework? I haven't specifically mentioned the general and the particular although it was part of the very first attempt I made to put a diagram together fifteen years ago. I have lost it since then but I intuitively feel that this point has great relevance although I can't 'fit' it in yet. I will need to think this through. Is it the same thing as primary/secondary? No - although I do think of the primary process as something like Jung's collective unconscious and therefore a way to tap into the general, I don't think the secondary process is necessarily particular to an individual. How about intuitive/reflective? No - although again intuition has the sense of tapping into an unstated set of recognizable features to make a judgment and reflection is the individual's particular take on a situation or thought. This would explain why intuition is often right but not infallible. Perhaps it is part of the overall integration/differentiation spectrum and doesn't belong to any particular parameter. Later: This relation of part to whole is a key for sustainability and it is the link that brings context into play and which is supported by the most recent conclusions on right and left brain research. "It's this specialization that contributes to one side being good for the analysis of small elements, versus the synthesis or holistic vision...I still like text and context" (Ornstein 1997, 175). This seems to make the most sense. I'll check it out by testing it in synthesis/analysis. Synthesis is when we pull things together often without having a specific end in sight. I suppose we do this based on experience and a certain faith that something will come out of it (like my data analysis by constant comparison where I analyzed the data into bits and then tried to synthesize the bits into wholes). Analysis is when we pull things apart and examine the particular bits looking for commonalties - is that a cluster of probabilistic features? Perhaps yes. Integration/differentiation doesn't seem right because when you integrate you are not necessarily*

*generalizing although differentiation is about noting the particulars of a situation. Perhaps integration does imply generalization since it takes you to a higher level of schema. Not really - because the higher level can be about a particular thing. This doesn't 'fit' yet. Are they strange attractors? Does the particular attract energy? yes - rf. the pictures the students brought to inspire them, also the 'wonderful idea of the monastery'.*

*The facilitator at the building B workshop was an attractor for the project team - he acted as a catalyst. (Later rereading this I suddenly see (AHA) that it is these catalysts that are the key factor in instigating the click which (referring back to Jantsch's diagram) requires a great input of energy. The catalysts (mode excitors) I have identified so far are: time pressure, excitement/frustration, and situation.) I think that many of the workshop participants were already on board at a general level and Bob brought the broad issues down to a personal level by asking individuals to share particular circumstances with each other and then made them believe that they could design a special building (he used the word brilliant). Does the general attract energy? yes - rf. the idea of allegiance to a country which is a cluster of probabilistic features that uniquely characterizes that configuration satisfying the global condition of national entity. I love mothers and I love my mother. But what exactly does that mean - an attractor? I refer to Gleick: "The boundary is where points are slowest to escape the pull of the set. It is as if they are balanced between competing attractors, one at zero and the other, in effect, ringing the set at a distance of infinity. The boundary between two or more attractors in a dynamical system served as a threshold of a kind that seems to govern so many ordinary processes, from the breaking of materials to the making of decisions (Gleick, 233)." This sounds more like the change agent/conserving agent hump on the Jantsch diagram. That's the threshold (boundary) and the attractors are the change and conserving agents? Seems right so far. Change is exciting when you're ready for it but stability is really appealing when you're in a state of flux. More Gleick - "This branch of dynamics concerns itself not with describing the final, stable behaviour of a system but with the way a system chooses between competing options. (ibid., 233)" A pinball machine works under one parameter (the pull of the plunger). Add a second parameter (or degree of freedom) like tilting the table and the plotting of the movement of the ball becomes really complex. Each equilibrium state is an attractor and the prediction of the outcome of the dynamics is impossible for*

*behaviour near the boundary. Gleick quotes Farmer: "On a philosophical level, it struck me as an operational way to define free will, in a way that allowed you to reconcile free will with determinism. The system is deterministic but you can't say what it's going to do next...the important problems out there in the world had to do with the creation of organization, in life or intelligence, but how do you study that?" (ibid., 251)*

*Every time I read these bites on CAS I get really excited. My intuition tells me that there's something of value there and each time I study the concepts I understand them more clearly and can see better how they mesh with my experiential knowledge. So, where does this section (general and particular) 'fit' in my model? Well, provisionally I am in favour of the change agent/conserving agent scenario.*

*Next day: I have not thought about any of this in detail since yesterday. I refer to Gleick's book to try and pick up the threads from yesterday. I start reading randomly and I see this quote: "Those studying chaotic dynamics discovered that the disorderly behaviour of simple systems acted as a creative [original emphasis] process. It generated complexity" (ibid., 43). Just before this quote there is a description of how erratic behaviour comes from a nonlinear twist in the flow of energy in and out of a simple oscillator (a playground swing). "The swing is damped and it is driven: damped because friction is trying to bring it to a halt, driven because it is getting a periodic push. Even when a damped driven system is at equilibrium, it is not at equilibrium, and the world is full of such systems" (ibid., 43). This is exactly how I conceive of the design process - damped and driven. And I feel that it is when the tension of the damped and the driven are about equal that dynamic equilibrium occurs. Too much damping and equilibrium or stagnation occurs, too much driving and chaos occurs but out of chaos comes the new level of integration or creativity. All this confirms for me that I'm at least on the right track. There's damping energy and there's driving energy: conserving agents and change agents. Attractors? Back to yesterday. I need a clearer definition of an attractor. But first I check out a previously marked page of Gleick's at the back of the book. It is where he talks about snowflakes and why they are all different. Scientists only recently discovered how to incorporate a second process into their calculations of the process of their formation. In addition to the diffusion of heat released when water freezes there is the force at work from surface*

tension. "The heart of the new snowflake model is the essence of chaos: a delicate balance between forces of stability and forces of instability"(ibid., 309).

Last week I was looking at an enormous pumpkin at the corner shop where they have a contest every year to guess the weight and win the pumpkin. I'm used to thinking of pumpkins as round but this one was blob-shaped and had definite tendencies to middle-aged spread. I wondered why it wasn't round. I realized that at some point when a pumpkin gets too big the force coming from the growth inside can't overcome the force of gravity in order to form the round shape. The pumpkin shape succumbs to the outside forces. I thought of this as a good analogy for design process where integration (alpha) interacts with differentiation (beta) to develop a design. I need to reconsider attractors. Ian Stewart's definition: "attractors are the things that the dynamics converge toward if you wait long enough; but once they reach the attractors, they promptly diverge again - and drastically...think of a Ping-Pong ball in an ocean, with complicated currents at the surface. If you release the ball from below the surface, it floats upward. If you drop it from above, it falls downward. It is attracted to the surface, no matter where it starts. But once on the surface, it is buffeted to and fro by the currents. The ocean surface is the attractor and the ball always ends up there; but the dynamics on the surface can be very complex and unpredictable. Attractors are emergent phenomena in dynamical systems." (Stewart, 206). This is the best metaphor I have come across yet. That last part about attractors being emergent phenomena is key. So it seems that the general and the particular may well be attractors. The general could be a sink attractor and the particular could be the source attractor. Stewart goes on "so when we use attractors as images for, say, evolution, we're not trying to suggest that the system 'knows in advance where it's going'. All we're saying is that the dynamical systems push it around according to certain rules" (ibid., 207).

The more I mull this over the more it seems right - generalities are reliable - we fall back on them when things are tough, they are our way of looking at the whole. Some extracts from the diaries are relevant: "I know it's important to talk about goals", "I personally believe in teamwork and a multi-disciplinary approach", "We need to define the problem." "At this point we were only discussing individual components of the building and losing track of the overall design philosophy".

*After this lengthy detour I need to get back to the analysis of the main point. Are the general and particular what should be discussed under this heading? Does the general sum up the cluster of probabilistic features? Ruelle doesn't mention the particular but isn't it the corollary of the probabilistic features? If certain overall characteristics are present doesn't that imply that other more individualistic characteristics are also present? I think so.*

In the project delivery process certain overall characteristics are present: group communication, shared information, common purpose, individual skills and experience in a range of areas. These are the global condition of a project in process. In determining the key differences in the process that lead to excellence in the outcome one must look at the global conditions. If the global conditions are not initially favourable or change negatively during the process due to inputs, then the *particular* manifestation of the outcome will be not be favourable even though the general outcome will have the same cluster of probabilistic features. This observation makes it clear how important it is to attempt to identify the detailed specifications of the global conditions that are likely to lead to successful outcomes. A Guide to the Project Management Body of Knowledge and the ISO 9000 Quality Management Program attempt to generalize the global conditions but both do so in an abstract and linear way. Both documents are important developments as they specify the components of successful project delivery but they are almost mute on the dynamics of the process. They promise a science of project management but have neglected to acknowledge its nonlinear nature.

*I need to check here again on the meaning of nonlinear to make sure it 'fits' with what I intend to say. Cohen and Stewart (1994) argue that the apparent paradoxes of irreversibility and linearity rest upon an inadequate understanding of the role of context (ibid., 248). "Laws of nature are not eternal, abstract truths. They are patterns that prevail in some chosen context: the laws that you find depend on the questions that you ask. And not just in physics and chemistry." "To understand something is to simplify it...what use is science if all it can do is complicate your view of the world. Every scientist should be trying to see the world in the simplest possible way"(ibid., 446). I've moved off linearity (I'm being nonlinear!). In an earlier book (Stewart 1989) says - an equation is linear if the sum of two solutions is again a solution. "The classical procedure is to linearize the nonlinear by throwing away all the awkward terms in*

*the equation...it's tacitly assumed that since the neglected terms in the equations are small - which is true - the difference between the linearized equation and that of the true equation must also be small - which remains to be seen" (ibid., 82). Not clear enough. Next I try Clayton and Radcliffe (1996,39). "Linear systems have two characteristics: the variation of the dependent variable on each of its control variables has a straight-line graph and the effect of each control variable is independent of the effects of any of the others...linear systems will not exhibit chaos, and will tend not to exhibit the same sort of critical behaviour as is seen in non-linear systems." All these are negative definitions. Coveney and Highfield (1995): "nonlinear systems do not obey the simple rules of addition...nonlinearity causes small changes on one level of organization to produce large effects at the same or different levels...this is familiar to most of us as positive feedback...in general nonlinearity produces complex and frequently unexpected results" (ibid., 9). This seems right. I like it!*

#### **4.2.5 Unpredictable Innovation**

The last characteristic of CAS is that of unpredictable innovation arising morphogenetically through mutually causal interactions and fluctuations. The research question which will be investigated under this characteristic is number 3: *does a project delivery and design process that uses the processes of CAS result in buildings or designs that are more creative?*

Morphogenesis is the development of biological pattern (Coveney, 3); the mechanism of the development of shape, structure and function in living things (ibid., 157). Morphogenesis can be thought of as the mechanism of the development of pattern in thoughts. Unpredictable innovation in thought can be speculated to arise from fluctuations of inputs to the brain along with the interactions between the inputs and the existing conditions within the brain. Thought of in this way, the brain becomes a mechanism for the co-evolution of the organism and its context. In terms of the individual, environmental inputs will affect the existing organization in minor or major ways as it reacts and adjusts to the incoming information. In terms of the group, environmental inputs also will affect the group as it develops its design proposal through shared decision-making. As well as the inputs to which the individual attends, the group has the additional environmental inputs of the other individuals in the group. It is this additional level of inputs

which makes group work either productive or destructive. The individuals in the group must be prepared to allow the input from the others to affect their own thinking and decision-making. If they are not prepared to do this then frustration will be the result as the others perceive their contribution being blocked. This may be the explanation for the many (47) energy/emotion comments in the diaries.

Some groups had individuals who felt that "our personalities are all quite co-operative and open-minded and no-one seems to have ego excess". One individual notes: "I have found that the two greatest problems in group projects are those people who lack discipline or energy and those who want to have control over everything". On the negative another notes: "As for the overall tone of the group, I'm feeling frustrated. \_ refuses to back down from what he would like to pursue." It is this tension between control and acquiescence between the individuals that provides the dynamic equilibrium at the group level. It should be stated that the control is an important component in group process. When it is missing, the group tends to move towards equilibrium. When the Blood group got into the lengthy and unproductive discussions over whether to tinker with their pretest design or do a new design, they could have made that decision very quickly and got on with their work. Instead they argued back and forward over the pros and cons of the two approaches until executing either was practically impossible due to time constraints. I would speculate that there was about equal strength in the voices for the two alternatives and that this led to the 'stalemate' that prevented the group from being productive.

One student very honestly foresaw this dilemma from the outset: "How will my wishes fit in? Since I am the only landscape architect I must be very strong in promoting my idea[s], but not too aggressive" and later summed it up: "the process created in the group, the reaction to others idea[s], need to compromise or to win". Another noted, rather ruefully, when the group split up to work individually: "of course there was a little less innovation because by working alone everyone stayed within his/her baggage of knowledge."

Examples of unpredictable innovation from the course diaries are: "\_ proposed an open cloister-like entry from street to courtyard. This is a milestone. We unanimously approve of the design", "The same ideas of interconnectedness and need for interaction jumped out at the whole group", "We reached a breakthrough in deciding that there will be two buildings", "suddenly \_ came with a form that seemed right and all the

pieces fall in place”, “Desperation. We as a group hit a ‘click’ (finally) and were able to carry through...to a conceptual design.”

In the case study, at the start-up workshop for building B there was a discussion about the lack of solar access to the site. The architects were concerned that with little southern (because of the shape of the site) and no western exposure (because of the proximity of the forest) they would have no solar opportunities. The mechanical engineer suggested that the team think of the forest as an asset. He suggested that it was a wonderful source of cool fresh air. From this statement, the basic diagram of the building was drawn: a section where the fresh air supply would be brought in low on the west side and moved upward through a series of atria to supply air throughout the building with very little mechanical ductwork. This observation from the mechanical engineer had a profound effect on the final form of the building and was the origination of one of the innovative features of the building.

Stephanie Bothwell, when asked if she had ever experienced a ‘click’ where a complex issue was solved through a sudden insight, thought carefully and then responded “Yes”. When asked for an example she talked at length about the experience of first reading the book A Pattern Language by Christopher Alexander (1977). “The strongest example is where actually I was reading Christopher Alexander’s Pattern Language and I realized that there was a whole window on the world that I had never been privileged to enter and it was very, very clear through...the way, the steps that he took you through and the examples that he gave and how he talked about the world and broke it into pieces and showed you that window of understanding and then you realized how the world was put together. In that instant I sort of got it all...all his books contain an incredible number of aha’s for me...Alexander’s seemingly soft aesthetic [has] a systematic and scientific thing that underlies it, but also that tradition of the way people have worked before must be studied to understand how to go forward and that language must be very, very communicable...shared. There’s no magic in that sense and yet in the combination of them and the putting together there’s magic. Always, over and over. Eternally... if it’s done correctly”. Also she tells of seeing the Seaside plan (a neo-traditional development) by Andres Duany and Elizabeth Plater-Zyberk for the first time: “looking at the Seaside plan, there was this one instant of recognition almost. It’s almost something

imprinted on me". These moments of unpredictable innovation seem to clearly have the quality of recognition about them. The explanation may lie in the phrase "plant the seeds when the ground is fallow". When Stephanie's state of mind had the appropriate combination of information and questions she was ready to perceive and absorb the worldview that Alexander presents in A Pattern Language and rearrange her own worldview to accommodate it. Similarly the 'recognition' of the Seaside plan speaks clearly to this sense of being able to recognize and accept information because of an internal readiness.

In the seminar questionnaire, when asked to rate the creativity of their own designs the participants responded as follows: in the pretest, out of a possible maximum total of 115 (23 responses multiplied by a maximum scale rating of 5), the groups rated their designs at 75 (65%). On the posttest, out of a possible maximum total of 85 (17 responses multiplied by 5), the groups rated their designs at 67 (79%). The groups assessed their second designs as slightly more creative. In answer to the question "did you experience a moment of insight during the design?" in the pretest, 18 said yes and 4 said no and in the posttest, 12 said yes and 4 said no. In answer to the question "did the group experience a moment of insight during the design?" in the pretest, 12 said yes and 11 said no. In the posttest, 11 said yes and 5 said no. After the manipulation of the independent variables, the participants felt that there was an increase in the creativity of the group but they felt that there was a decrease in the creativity of the individuals. This may have been due to the fact that the groups were developing better working relationships and that individuals felt it unnecessary to be individually creative or less able to identify their individual contributions. A related question: "Rate your personal level of input to the design proportionally" was answered at 91 out of a maximum of 115 (71%) in the pretest. In the posttest, the answer was 64 out of 85 (75%). It appears that there was no feeling that the degree of individual input was significantly different from pretest to posttest. A question asked only after the posttest for the trial group design (after the idea of 'clicks' had been introduced): "did you experience any clicks when designing?" was answered yes by 5 and no by 3. At the very least, the conclusion must be that the idea of 'clicks' is quite recognizable to designers and seems to occur fairly frequently.

			Sustainability	Technical Competence	Creativeness	Aesthetics
Trial	Full-Blown	Pretest	12	12	11	12
		Posttest	11	8	4	6
	Atlas Mountains	Pretest	10	10	9	8
		Posttest	6	5	3	3
	Stoneware	Pretest	4	4	12	11
		Posttest	3	1	5	7
Control	Halve	Pretest	4	6	10	9
		Posttest	1	3	8	10
	Gram Molecules	Pretest	8	11	7	4
		Posttest	7	8	6	5
	Blood	Pretest	2	2	1	1
		Posttest	9	7	2	2

TABLE 7 THE CONSENSUAL ASSESSMENT RESULTS FOR CREATIVITY (rank order - 1 is high)

The group design rated most creative by the consensual assessment method was the Blood group (control) pretest design and their posttest design was ranked the second most creative. Third ranked was the Atlas Mountains posttest (trial) and fourth was Full-Blown posttest (trial). Halve (control), which had the designs ranked first and fourth for sustainability, were eight and tenth for creativity. The Blood group pretest design was ranked second for sustainability. While the Halve group were judged to design well from the point of view of sustainability, their designs were not judged nearly as well from the point of view of creativity. Even though the Blood group shows a correlation between sustainability and creativity, none of the other groups show a similar correlation. Of more interest is the finding that all the groups showed an increase in creativity from the pretest to the posttest design with the exception of the Blood group who were practically equal. It seems that the manipulations were successful in raising the level of creativity in the designs. Furthermore the increases in the trial group were significantly greater than the increase in the control groups. While there is no statistical validity due to the small numbers it is nonetheless of interest that the trial group increases were all greater than the control group.

When asked whether the group approach was productive, in the pretest questionnaire 16 people said yes and 7 said no. In the posttest, 11 said yes and 6 said no. It seems that even though they felt their designs were more creative, they felt that the groups were less productive.

Unpredictable innovation does seem to arise from the interactions and fluctuations of information, inspiration and intention at both the individual and group levels. And out of this innovation comes the morphogenesis of the design process and ultimately the design product. This seems to affirm research question 2. If, as I noted earlier, creative is defined as new and of value, then in this sense, it can be seen that the processes of complex adaptive systems certainly result in creative design. The interactions of the participants and the interactions within the minds of the individuals will lead to innovation when the parameters are favourable. When the right information is available (whether it's pictures of roofs or heat loss calculations), change will occur. When additionally the individual and the group are inspired (by the internal (credit for the course) or external (the Director's talk) circumstances, change will occur. Finally, when the individual or group also decides on what they want to achieve then the likelihood of real creativity is highest. The design process will be high energy, productive and creative. Probably it will also produce more sustainable products.

## **Chapter Five**

### **Whence, Hence and Whither?**

#### *Outcomes and Recommendations for Further Research*

The more we come to understand the human information-processing systems epitomized by the human brain, the more we find them to be functioning as evolutionary systems, and the more we come to understand evolutionary systems, the more we discover them to be operating as information-processing machines.

George B. Dyson

[T]he nature of the linkage between genetic evolution and cultural evolution...is...one of the great remaining problems of the natural sciences. This part of the overlap of the two great branches of learning can be summarized as follows. We know that all culture is learned, yet its form and the manner in which it is transmitted are shaped by biology. Conversely, the genes prescribing much of behavioral biology evolved in a cultural environment, which was itself evolving. A great deal has been learned about these two modes of evolution viewed as separate processes. What we do not understand very well is how they are linked.

Edward O. Wilson

### **5.1 Summary of the Problem, the Analysis and the Research Undertaken**

The dissertation examines the present situation in the architectural profession, the existing project design process, and the shortcomings of the resultant product. The artifacts that designers are making under the present system constraints (mainly internal constraints) are contributing to ecological, social and economic problems at local, regional and global scales. To make buildings that are more sustainable designers ought to make links to the larger ecological, social and economic system constraints at all three levels of scale. It

is hypothesized that since evolutionary processes result in natural products that fit their environment, then design processes that more closely replicate evolutionary processes will result in artificial products that more closely fit their environment. Moreover, just as complex adaptive systems theory is a more general case of evolutionary theory and just as the processes of complex adaptive systems are capable of co-evolving with their environment, it is hypothesized that the products of design processes displaying those characteristics will be more adaptive i.e., will fit their environment over a long term.

There is a need for a new model of design, a model that explicitly includes a non-objectivist way of knowing while insisting on the importance of an objectivist approach. The great gains that science has brought to society must be fully utilized but the non-rational must also be allowed to influence our decision-making. Recognition must be given to the range of constraints that will operate on the design product and the designer must design an artifact that is capable of responding to those constraints and can change as the constraints change. Just as nature evolves existing processes and products by introducing novelty which is then tested by its environment through selection of the fittest, it is proposed that co-evolution of the design product and its environment is achieved through creativity in the design process and selection of the fittest conjectures.

In searching for a new model, I have looked at emerging issues in and of the behaviour of systems. I have attempted to integrate and synthesize information from natural science, social (behavioural science) and design science. Edward O. Wilson says "the central question of the social sciences is...the nature of the linkage between genetic evolution and cultural evolution. It also one of the great remaining problems of the natural sciences" (Wilson 1998, 2049).

Research was carried out in four case studies. Both quantitative and qualitative results were sought and affirmation/negation of the hypothesis was sought through 'triangulation' of the results. While it cannot be shown conclusively that use of the framework results in more adaptive products, it is very promising that the results have been mainly positive. The weight of the evidence is favourable that, at the very least, aspects of the framework seem to have positive effects on the outcomes of the process in terms of making environmental links. All the groups (except one) in the seminar increased the sustainability of their designs

after the information/inspiration/intention input. All the groups (except one) increased the creativity of their designs after the information/inspiration/intention input and the trial group (with exposure to the dynamics of the model) increased more significantly than the control group. The case study building (B) continues to receive recognition from around the world and was recently published in a book called Green Development by the Rocky Mountain Institute (1998).

The findings from the research are not conclusive. While there is confirmation in the results of the three studies, none have statistical validity due to the small numbers involved. As Lincoln and Guba say: "Naturalistic inquiry operates as an *open* system; no amount of member checking, triangulation, persistent observation, auditing, or whatever can compel; it can at best *persuade* [original emphasis]" (Lincoln and Guba 1985, 329). Naturalistic studies cannot be warranted in the same way as conventional studies. Nonetheless the research does appear to support the hypothesis with one exception. It was hypothesized that sustainable buildings would also be beautiful buildings. The seminar findings showed no correlation between sustainability and aesthetics as judged by consensual assessment.

While the research results are inconclusive, a major benefit of the study was testing the framework in use and the feedback received from the subjects was invaluable. The framework can now be itself evolved to describe more accurately the processes of the making of place.

The implications for current theory of design process are, at the very least, interesting and a modest contribution to knowledge of design process can be claimed. For project design process the results affirm recent developments in practice such as design-build and partnering.

The studies were limited by the low numbers of participants involved in the seminar and by the lack of control over the variables of personality and human circumstances such as ill health. The lack of independent data against which to compare the effect of the use of the model is a minor concern. This drawback is partly offset by the opportunity to observe and record emergent pattern in design process. The process is non-linear and cannot be observed in a linear manner.

The case study of the comparison of the university buildings was limited by the lack of access to some of the actual resource data (the utility meters were not operational) so the reported numbers are mainly projections. Actual operating data will be used to check validity of the projected figures as it becomes available.

## 5.2 Further Research

Human nature is not the genes, which prescribe it, or the universals of culture, which are its products. It is rather the epigenetic rules of cognition, the inherited regularities of cognitive development that predispose individuals to perceive reality in certain ways and to create and learn some cultural variants in preference to competing variants.

Edward O. Wilson

Two approaches for further research are possible. Either the model should be discarded or it should be modified to make it more comprehensible and more easily disseminated. The first approach is not reasonable given the sound theoretical base that has been developed for the model, as well as the encouraging results from the case studies. The author feels strongly that there is potential in pursuing further development of the framework.

The framework needs modification and further testing with practitioners and with educators in order to gain more feedback and to develop ways of disseminating it on a widespread basis.

The CAS framework has proved productive in the development of the abstract model. The model is conceptually sound but needs to be operationalized so that it becomes relevant to practitioners and can be seen as an aid in practice. More clarity and comprehensibility needs to be developed in communication of the model to practitioners. It is to be expected that new ideas will take time to become disseminated. They need to be comprehended and tested for usefulness before being adopted.

The development of the model makes a contribution to knowledge of design process. For the first time, to the knowledge of the author, a design process model is proposed which acknowledges the dynamics of

design process and explicitly explores emergence in that context. Thus, it has positive value for discussion and information sharing by design researchers.

## 5.3 Conclusion

Given the immense complexity of the numerous interlocking issues facing humanity, foresight demands the ability to identify and gather great quantities of relevant information; the ability to catch glimpses, using that information, of the choices offered by the branching alternative histories of the future, and the wisdom to select simplifications and approximations that do not sacrifice the representation of critical qualitative issues, especially issues of values.

Murray Gell-Mann

Evolution has been the key ingredient in my exploration of sustainability in project delivery and design process. Our ability as humans to adapt the natural world to our perceived needs has accelerated and the slow incremental development of place in indigenous society has given way to an abstracted process that largely ignores the full range and complexity of environmental constraints. The key question now is: how can buildings be designed to be more adaptive? I have argued that a more adaptive product will result from a project design process that is more focused on relevant environmental information, is more inspired to provide a good environmental fit and which uses specific targets related to environmental performance. I have further argued that the project design process is a complex adaptive system and it will result in better adapted products when it more closely conforms to the processes of natural systems. In the design system, the conserving agents (heredity, adaptation, and confirmation) work along with the change agents (variation, novelty, and shock to the system) to differentiate and integrate the parts of the system. The boundary-breaking processes (crossover, emergence and selection, and self-organization) move the system from one level to another. When a part of a system is at a lower level in a hierarchy it forms the *content* for the *context* of the next level. So, a part of a whole acts both as content for the level above it (it is a part of a whole) and as context for the level below it (it is the whole which is made up of parts). I have attempted to identify these processes and levels for the particular circumstances of design.

In excellent science and in excellent art the common element is great attention to the subject of study. Scientists tend to study their subject through *differentiation* and artists tend to study their subject through *integration*. However, good art and good science use both to reach their ends. When a subject of study in science is tackled from a purely quantitative, analytical, objectivist approach, the result is differentiated and unconnected 'pieces' of data. An act of integration is required in order to 'fit' the data to its context. Similarly, when a subject of study in art is tackled from a purely integrative or qualitative approach the result is a romantic and sentimental view of the content. The lack of rigor (that can be satisfied by differentiation of the content) detracts from the power of the work of art. Great design similarly requires attention to both modes of operation: differentiation of content and integration to context.

In architecture, the content (economic, social and ecological) is the building and the context (economic, social and ecological) is the environment within which the building is situated. It is the mediation between the content and the context that is the territory of the project team. How will the content be formed to 'fit' the context? It is here that Simon's notion of the science of the artificial is helpful. At work on a design, the design team is constructing conjectural 'fits' between the content and the context. This artificial conjecture during the design process leads ultimately to the 'real' content in the 'real' context. Viewed in this way, it is obvious that artificial conjectures (designs) which ignore aspects of the real content or context will result in buildings that lack 'fit' in those aspects. In this sense, these buildings will not be adaptive.

When Christopher Alexander talks about *the pattern which connects* he is referring to this aspect of the 'fit' of a good building to its economic, social and ecological context. The project team must be able to perceive *the pattern which connects* and to work together using their specialist knowledge to design a building which responds to its context and which has the right content. In order to do this the team needs to direct its attention to both the content and the context (ecological, social and economic) of the project. The particular aspects of a team member's expertise with both content and context will allow their input to be contributory to the design product. Expertise provides shortcuts to knowledge (*information*) about the content and the context of a particular project. For example, the planner for a project area will have a deep

knowledge of the physical and social context of a project. The mechanical engineer will have a deep knowledge of the content requirements for temperature and humidity. The structural engineer will have a deep knowledge of the content requirements for materials strength and span configurations. The owner will have a deep knowledge of the economic context and content of the project. It is only by coming together at the start of a project to share their own areas of knowledge that a project team can hope to perceive *the pattern which connects*. The pattern which connects must be present in all three areas: economic, social and ecological. Western society has developed great skill in perceiving the pattern which connects the economic content and context. Pro forma economic analysis gives a developer an easy tool for assessing the profit to be gained from a project. The motivation (*inspiration*) of profit is compelling. The social content and context has also received attention but to a lesser degree. Methods for 'controlling' development to suit a social context have been developed by the urban planning profession and similarly methods of 'programming' the social content of a project have been developed by architectural programmers. These have been successful to a degree but seem as yet to be incapable of handling the full complexity of human affairs in an adaptive manner. The ecological content and context are the least successfully handled. There has been little recognition by project teams that either the content of the project or the context of the project has an ecological component. Recent efforts to promote green buildings are starting to engage these issues by quantifying the effects of designs on the ecological content and context of a project. Assessment systems such as BEPAC (Cole, Rousseau, et al. 1993 ) attempt to address the existing shortcoming but there is still much work to be done.

Human need has intersected with the human ability to adapt the earth's resources to its own ends. Today this ability has developed to the point where want becomes need and resources are perceived as infinite. The intimate relationship that used to exist between humans and their environment where the effects of one's actions were readily apparent has been overwhelmed by the artificial world's domination of nature. The effect has been to alienate us from the intimate connection between what we do and its effect on human and natural systems. We can no longer perceive the connection between the materials of the chair we sit in and the natural world of plants and trees that it came from. We cannot see the effects of our actions on the land. This distancing is at work in the development and operation of buildings. We are

rarely aware of the effect of our resource manipulations on the very earth that supplies the resources. This connection to the consequences of design decisions on natural systems must be reinvigorated. The application of the control parameters of information, inspiration and intention can realize this reconnection. Those who have already made these reconnections in their lives are impatient to find new ways to define our placemaking in the world. They are primed and wait only for the catalysts that will energize change and release their creativity.

In the dissertation I have shown that a CAS project design process is an important component in the design of a sustainable future. Information, inspiration and intention are the necessary catalysts. The energy needed to make the required changes in project design process will come from the *information* that we possess about the effects of our actions on human and physical systems. As we incorporate this into *knowledge* it will *inspire* us to develop the *motivation* that will allow us to form specific *intentions* which can be then be *operationalized*. We will be driven by the excitement of change agents and damped by the homeostasis of the conserving agents. To excite is *to raise a system to a higher energy level* (Landau 1968). This higher energy level is the means to boundary-breaking and transition to the next level. We humans must learn to break the artificial boundaries between the natural world and ourselves if we are to survive the economic, social and ecological dilemmas which face us. And architects must learn to see buildings as artificial insertions into natural systems and understand how to design their artifices in ways that generate productive possibility instead of destructive determinism.

### Sources Consulted

- Adams, James L. 1986. The care and feeding of ideas: A guide to encouraging creativity. Reading, Massachusetts: Addison-Wesley Publishing Company, Inc.
- Ahl, Valerie and T. F. H. Allen. 1996. Hierarchy theory: A vision, vocabulary, and epistemology. New York: Columbia University Press.
- Alexander, Christopher. 1964. Notes on the synthesis of form. Cambridge, Massachusetts: Harvard University Press.
- \_\_\_\_\_. 1979. The timeless way of building. New York: Oxford University Press.
- Amabile, Teresa M. 1983. The social psychology of creativity. New York: Springer-Verlag.
- Amabile, Teresa M. and Margaret L. Stubbs. 1982. Psychological research in the classroom: Issues for educators and researchers. New York: Pergamon Press.
- Arieti, Silvano. 1976. Creativity: The magic synthesis. New York: Basic Books.
- Attoe, Wayne. 1978. Architecture and critical imagination. Chichester: John Wiley & Sons.
- Bateson, Gregory. 1979. Mind and nature: A necessary unity. New York: E.P. Dutton.
- \_\_\_\_\_. 1972. Steps to an ecology of mind: Collected essays in anthropology, psychiatry, evolution and epistemology. San Francisco: Chandler Publishing Company.
- Bender, Thomas. Winter 1994. The cultures of intellectual life. The Kettering Review: 46-52.
- Benevolo, Leonardo. 1977. History of modern architecture. Cambridge, Massachusetts: M.I.T. Press.
- Berlyne, Daniel E. 1971. Aesthetics and psychobiology. New York: Appleton-Century-Crofts.
- Boden, Margaret A. 1990. The creative mind: Myths and mechanisms. London: BasicBooks.
- Bogdan, Radu J. 1997. Interpreting minds. Cambridge, MA: MIT Press.
- Boulding, Kenneth E. 1977. The image: Knowledge in life and society. Ann Arbor: The University of Michigan.
- Boyle, Bernard Michael. 1977. Architectural practice in America, 1865 - 1965 - ideal and reality. The architect, Editor Spiro Kostof. New York: Oxford University Press.
- Brand, Stewart. 1994. How buildings learn: What happens after they're built. New York: Penguin Books.
- Brink, Jean R. and C. Roland Haden. 1989. The computer and the brain: Perspectives on human and artificial intelligence. Editorial Assistant Christopher Burawa. Amsterdam: Elsevier Science Publishers.
- Brolin, Brent C. 1976. The failure of modern architecture. New York: Van Nostrand Reinhold Company.
- Brown, Lester. 1995. Nature's limits. New York: W. W. Norton & Company.
- Brown, Lester R., Christopher Flavin, and Hal Kane. 1996. Vital signs 1996. New York: W. W. Norton &

Company.

- Buchanan, Richard and Victor Margolin. 1995. Discovering design: Explorations in design studies. Chicago: The University of Chicago Press.
- Bullock, Alan, Oliver Stalleybrass, and Stephen Trombley. 1988. The Fontana dictionary of modern thought. second ed. London: Fontana Paperbacks.
- Bullock, G. N. and others. 1995. Developments in the use of the genetic algorithm in engineering design. Design Studies 14, no. 4: 507-24.
- Campbell, D. T. 1960. Blind variation and selection retention in creative thought as in other knowledge processes. Psychological Review, no. 67: 380-400.
- Capra, Fritjof. 1996. The web of life: A new scientific understanding of living systems. New York: Doubleday.
- Carson, Paula Phillips and Kerry D. Carson. 1993. Managing creativity enhancement through goal-setting and feedback. The Journal of Creative Behavior 27, no. Number 1: 36-45.
- Chalmers, David J. December 1995. The puzzle of conscious experience. Scientific American: 80-6.
- Churchland, Patricia Smith. 1996. Neurophilosophy: Toward a unified science of the mind/brain. Cambridge, MA: MIT Press.
- Clayton, Anthony M. H. and Nicholas J. Radcliffe. 1996. Sustainability: a systems approach. Boulder, Colorado: Westview Press, Inc.
- Coady, Teresa. November-95. Designing whole buildings: The C-2000 program integrates the design process. Advanced Buildings Newsletter 1, no. 10: 12-5.
- Cohen, Jack and Ian Stewart. 1994. The collapse of chaos: Discovering simplicity in a complex world. New York: Penguin Books.
- Cole, Ray, David Rousseau, and Ian Theaker. 1993. Vancouver, B.C.: BEPAC Foundation.
- . 1971. Toronto, Ontario: The Queen's Printer.
- Coveney, Peter and Roger Highfield. 1995. Frontiers of complexity: The search for order in a chaotic world. New York: Fawcett Columbine.
- Cross, Nigel. October 1997. Descriptive models of creative design: Application to an example. Design Studies 18, no. 4: 427-40.
- Cuff, Dana. 1992. Architecture: The story of practice. Cambridge, Massachusetts: The MIT Press.
- Cziko, Gary. 1995. Without miracles: Universal selection theory and the second Darwinian revolution. Cambridge, Massachusetts: The MIT Press.
- d'Aquili, Eugene D. and Hans Mol. 1990. The regulation of physical and mental systems: Systems theory of the philosophy of science. Lewiston: The Edwin Mellen Press.
- Daniels-McGhee, Susan and Gary A. Davis. Third Quarter, 1994. The imagery-creativity connection. The

Journal of Creative Behavior 28, no. Number 3: 151-76.

- de Bono, Edward. 1985. De Bono's thinking course. New York: Facts on File Publications.
- Deci, Edward L. May 1992. On the nature and functions of motivation theories. Psychological Science 3, no. No. 3: 167-71.
- Dennett, Daniel C. 1991. Consciousness explained. Boston: Little, Brown and Company.
- \_\_\_\_\_. 1995. Darwin's dangerous idea: Evolution and the meanings of life. New York: Simon and Schuster.
- Denzin, Norman K. 1994. The art and politics of interpretation. The handbook of qualitative research.
- Dias, W. P. S. and D. I. Blockley. 1994. The integration of product and process models for design. Design Studies 15, no. 4: 417-32.
- Duncan, William R., Director of Standards. 1996. Upper Darby, PA: Project Management Institute.
- Dutton, Thomas A. 1991. Architectural education and society: An interview with J. Max Bond, Jr. Voices in architectural education, Editor Thomas A. Dutton. New York: Bergin & Garvey.
- Dyson, George B. 1997. Darwin among the machines: The evolution of global intelligence. Reading, Massachusetts: Addison-Wesley Publishing Company Inc.
- Easterby-Smith, Mark, Richard Thorpe, and Andy Lowe. 1991. Management research: An introduction. London: Sage Publications.
- Ebert II, Edward S. Fourth Quarter, 1994. The cognitive spiral: Creative thinking and cognitive processing. The Journal of Creative Behavior 28, no. Number 4: 275-90.
- Edelman, Gerald M. 1992. Bright air, brilliant fire: On the matter of the mind. New York: HarperCollins Publishers Inc.
- Ericsson, K. Sanders and Herbert A. Simon. 1993. Protocol analysis: Verbal reports as data. Revised Edition ed. Cambridge, Massachusetts: The MIT Press.
- Finke, R. A., T. B. Ward, and S. M. Smith. (1992). Creative cognition: Theory, research, applications. Cambridge, MA: MIT Press.
- French, M. J. 1988. Invention and evolution: Design in nature and engineering. Cambridge: Cambridge University Press.
- Fried, George H. 1990. Theory and problems of biology. New York: McGraw-Hill Publishing Company.
- Gell-Mann, Murray. 1994. The quark and the jaguar: Adventures in the simple and the complex. New York: W. H. Freeman and Company.
- Giddens, Anthony. 1990. The consequences of modernity. Stanford, California: Stanford University Press.
- Glanville, Ranulph. Feb 1998. Keeping faith with the design in design research. Designing design research 2: The design research publication cyberbridge - 4D designweb:  
<http://www.dmu.ac.uk/dept/schools/des-man/4dd/drs2.html>.

- Gleick, James. 1993. Genius: The life and science of Richard Feynman. New York: Vintage Books.
- Gnuse, Robert. December 1990. Contemporary evolutionary theory as a new heuristic model for the socioscientific method in biblical studies. Zygon 24, no. 4: 405-31.
- Goertzel, Ben. 1993. The evolving mind. U.S.A.: Gordon and Breach.
- Goldschmidt, Gabriella. 1995. The designer as a team of one. Design Studies 16, no. 2: 189-209.
- \_\_\_\_\_. 1983. Doing design, making architecture. Journal of Architectural Education 37, no. 1 (Fall): 8-13.
- Goodman, Robert. 1971. After the planners. New York: Simon & Schuster.
- Gregory, Richard. 1987. Intelligence based knowledge: Knowledge based on intelligence. Creative intelligences, Editors Richard Gregory and Pauline K. Marstrand. London: Frances Pinter (Publishers).
- Gregory, Richard and Pauline K. Marstrand. 1987. Creative intelligences. London: Frances Pinter.
- Grossman, Stephen R. Fourth Quarter, 1994. Transcendence as a subset of evolutionary thinking: A Darwinian view of the creative experience. The Journal of Creative Behavior 28, no. Number 4: 227-38.
- Grossman, Stephen R. and Edward E. Wiseman. First Quarter 1993. Seven operating principles for enhanced creative problem solving training. The Journal of Creative Behavior 27, no. Number 1: 1-17.
- Gruber, H. E. and S. Davis. 1988. Inching our way up Mount Olympus: The evolving systems approach to creative thinking. The nature of creativity, Editor R. Sternberg, 243-70. Cambridge, MA: Cambridge University Press.
- Gusevich, Miriam. 1995. Architecture and its dis-contexts. Architecture and Legitimacy, editors Hans van Dijk and Liesbeth Janson. Rotterdam: NAI Publishers.
- Gustafson, Roland and Torsten Norlander. Second Quarter, 1994. Effects of alcohol on persistent effort and deductive thinking during the preparation phase of the creative process. The Journal of Creative Behavior 28, no. Number 2: 124-32.
- Hardin, Garrett. 1968. The tragedy of the commons. Science, no. 162: 1243-8.
- Hare, Paul A. 1992. Groups, teams and social interaction: Theories and applications. New York: Praeger.
- Harth, Erich. 1993. The creative loop: How the brain makes a mind. Reading, Massachusetts: Addison-Wesley Publishing Company.
- Hofstadter, Douglas and the Fluid Analogies Research Group. 1995. Fluid concepts and creative analogies: Computer models of the fundamental mechanisms of thought. New York: BasicBooks.
- Holland, John H. 1998. Emergence: From chaos to order. Reading, Massachusetts: Addison-Wesley Publishing Company, Inc.
- \_\_\_\_\_. 1995. Hidden order: How adaption builds complexity. Reading, Massachusetts: Addison-Wesley Publishing Company.

- Hollenbeck, John R. and others. 1989. Investigation of the construct validity of a self-report measure of goal commitment. Journal of Applied Psychology 74, no. No. 6: 951-6.
- Hooker, C. A. 1995. Reason, regulation, and realism: Toward a regulatory systems theory of reason and evolutionary epistemology. Albany, NY: State University of New York Press.
- Isaksen, Scott G., Gerard J. Puccio, and Donald J. Treffinger. Third Quarter, 1993. An ecological approach to creativity research: Profiling for creative problem solving . The Journal of Creative Behavior 27, no. Number 3: 149-70.
- Jantsch, Erich. 1975. Design for evolution: Self-organization and planning in the life of human systems. New York: George Braziller.
- Jones, John Christopher. 1988. Softecnic. Design after modernism, Editor John Thackara, 216-26 Thames and Hudson.
- Judson, Horace Freeland. 1987. The search for solutions. Baltimore: The John Hopkins University Press.
- Kantorovich, A. 1993. Scientific discovery: Logic and tinkering. Albany, NY: State University of New York Press.
- Kaplan, Rachel and Stephen Kaplan. 1989. The experience of nature: A psychological perspective. Cambridge: Cambridge University Press.
- Kauffman, Stuart A. 1993. The origins of order: Self-organization and selection in evolution. New York: Oxford University Press.
- Kaufmann, Edgar. 1955. An American architect: Frank Lloyd Wright. New York: Horizon Books.
- Kelso, Scott. 1995. Dynamic patterns: The self-organization of brain and behaviour. Cambridge, Massachusetts: The MIT Press.
- Koestler, Arthur. 1964. The act of creation. London: Pan Books Ltd.
- Kostoff, Spiro. 1977. The architect. New York: Oxford University Press.
- Krohn, Wolfgang and Gunter Koppers. 1990. Science as a self-organizing system: Outline of a theoretical model. Selforganization: Portrait of a scientific revolution Wolfgang Krohn, Gunter Koppers, and Nowotny Helga, 208-21. Dordrecht: Kluwer Academic Publishers.
- Krohn, Wolfgang, Gunter Koppers, and Nowotny Helga. 1990. Selforganization: Portrait of a scientific revolution. Dordrecht: Kluwer Academic Publishers.
- Kroll, Lucien. 1987. An architecture of complexity. translator Peter Blundell Jones. Cambridge, Massachusetts: The MIT Press.
- Kuhn, Robert Lawrence and George Thomas Geis. 1985. Creativity and commitment: Modeling meaning and mission for individuals and institutions. Frontiers in creative and innovative management, Editor Robert Lawrence Kuhn, 113-57. Cambridge, Massachusetts: Ballinger Publishing Company.
- Kuhn, Thomas S. 1970. The structure of scientific revolutions. 2nd ed. Chicago: The University of Chicago.
- Koppers, Bernd-Olaf. 1990. On a fundamental paradigm shift in the natural sciences. Selforganization: Portrait of a scientific revolution, editors Wolfgang Krohn, Gunter Koppers, and Helga Nowotny.

Dordrecht: Kluwer Academic Publishers.

- Lakoff, George. 1987. Women, fire, and dangerous things: What categories reveal about the mind. Chicago: The University of Chicago Press.
- Landau, Sidney I. 1968. Funk and Wagnalls: Standard college dictionary. New York: Funk and Wagnalls.
- Lawson, Brian. 1994. Design in mind. Oxford: Butterworth-Heinemann Ltd.
- Leclair, Kim and David Rousseau. 1992. Environmental by design: A sourcebook of environmentally aware interior material choices. Vancouver: Hartley and Marks.
- Lenssen, Nicholas and David Malin Roodman, authors. 1995. Making better buildings. New York: W. W. Norton & Company.
- Lewin, Roger. 1992. Complexity: Life at the edge of chaos. New York: Macmillan Publishing Company.
- Lincoln, Yvonna S. and Egon G. Guba. 1985. Naturalistic Inquiry. Newbury Park London: Sage Publications.
- Locke, Edwin A. and Gary P. Latham. 1990. A theory of goal setting and task performance. Englewood Cliffs, New Jersey: Prentice Hall.
- Lyle, John Tillman. 1994. Regenerative design for sustainable development. New York: John Wiley & Sons, Inc.
- Mackinder, Margaret and Heather Marvin. 1982. Design decision making in architectural practice : The roles of information, experience and other influences during the design process. York, England: University of York.
- Manning, Peter, Lecture. 1968. Vancouver: University of British Columbia.
- Manzini, Ezio. 1995. Prometheus fo the everyday: The ecology of the artificial and the designer's responsibility. Discovering design: Explorations in design studies, Editor Richard Buchanan and Victor Margolin. Chicago: The University of Chicago Press.
- Maslow, A. H. 1986. The farther reaches of human nature. New York: Penguin Books.
- May, Rollo. 1975. The courage to create. Toronto: Bantam Books.
- McCorduck, Pamela. 1979. Machines who think: A personal inquiry into the history and prospects of artificial intelligence. San Francisco: W. H. Freeman and Company.
- Mitcham, Carl. 1995. Ethics into design. Discovering design: Explorations in design studies, Editor Richard Buchanan and Victor Margolin. Chicago: The University of Chicago Press.
- Mitchell, Thomas C. 1993. Redefining designing: From form to experience. New York: Van Nostrand Reinhold.
- Monod, Jacques. 1972. Chance and necessity: An essay on the natural philosophy of modern biology. New York: Vintage Books.
- Mumford, Michael D., Roni Reiter-Plamon, and Matthew R. Redmond. 1994. Problem construction and cognition: Applying problem representations in ill-defined domains. Problem finding, problem

- solving, and creativity, Editor Mark A. Runco, 3-39. Norwood, New Jersey: Ablex publishing Corporation.
- Nowak, Martin A., Robert M. May, and Karl Sigmund. June 1995. The Arithmetics of mutual help: Computer experiments show how cooperation rather than exploitation can dominate in the Darwinian struggle for survival. Scientific American: 76-81.
- Nowotny Helga. Actor-networks vs. science as a self-organizing system: A comparative view of two constructivist approaches. Selforganization: Portrait of a scientific revolution Wolfgang Krohn and Gunter Koppers, 223-37.
- O'Neill, Sharon and Doris Shallcross. Second Quarter, 1994. Sensational thinking: A teaching/learning model for creativity. The Journal of Creative Behavior 28, no. Number 2: 75-88.
- Odum, Howard T. 1994. Ecological and general systems: An introduction to systems ecology. revised ed. Niwot, Colorado: University Press of Colorado.
- Ornstein, Robert. 1997. The right mind: Making sense of the hemispheres. New York: Harcourt Brace & Company.
- Orr, David W. 1992. Ecological literacy: Education and the transition to a postmodern world. Albany: State University of New York Press.
- Penrose, Roger. 1990. The emperor's new mind: Concerning computers, minds, and the laws of physics. London: Vintage Books.
- Polanyi, Michael. 1962. Personal knowledge: Towards a post-critical philosophy. Chicago: The University of Chicago Press.
- Press, Joseph. May 1998. Soul-searching: Reflections from an ivory tower. Journal of Architectural Education 51, no. 233: 244.
- Prigogine, Ilya and Isabelle Stengers. 1984. Order out of chaos: Man's new dialogue with nature. Toronto: Bantam Books.
- Pye, David. 1964. The nature of design. London: Studio Vista.
- Rachels, James. 1990. Created from animals: The moral implications of Darwinism. Oxford: Oxford University Press.
- Rickards, Tudor. First Quarter 1993. Creative leadership: Messages from the front line and the back room. The Journal of Creative Behavior 27, no. Number 1: 46-56.
- Rose, Gilbert R. 1992. The power of form: a psychoanalytic approach to aesthetic form. Madison: International Universities Press.
- Roth, Gerhard and Helmut Schwegler. 1990. Selforganization and the unity of the world. Selforganization: Portrait of a scientific revolution, editors Wolfgang Krohn, Gunter Koppers, and Helga Nowotny. Dordrecht: Kluwer Academic Publishers.
- Rothbart, Harold A. 1972. Cybernetic creativity. New York: Robert Speller & Sons, Publishers, Inc.
- Rothenberg, Albert. 1979. The emerging goddess. Chicago: University of Chicago Press.

- Ruelle, David. 1991. Chance and Chaos. Princeton, New Jersey: Princeton University Press.
- Runco, Mark A. 1994. Problem finding, problem solving, and creativity. Norwood, New Jersey: Ablex Publishing Corporation.
- Rybczynski, Witold. 1986. Home: A short history of an idea. New York: Viking.
- Schon, Donald A. 1985. The design studio: An exploration of its traditions and potentials. London: RIBA Publications.
- \_\_\_\_\_. 1983. The reflective practitioner: How professionals think in action. New York: Basic Books, Inc.
- \_\_\_\_\_. 1977. Theory in practice: Increasing professional effectiveness. San Francisco : Jossey-Bass.
- Simon, Herbert. 1979. The sciences of the artificial. Cambridge, Massachusetts: The MIT Press.
- Smuts, General the Right Hon. J. C. 1926. Holism and evolution. Westport, Connecticut: Greenwood Press.
- Stewart, Ian. 1989. Does God play dice? The new mathematics of chaos. New York: Penguin Books Inc.
- Strohman, Richard C. March 1997. The coming Kuhnian revolution in biology. Nature Biotechnology 15: 194-200.
- Thayer Jr., Robert L. 1994. Gray world, green heart: Technology, nature, and the sustainable landscape. New York: John Wiley & Sons, Inc.
- Thomas, Bruce. May 1997. Culture, merchandise, or just light entertainment? New architecture at the millennium. Journal of Architectural Education 50, no. Number 4: 254-64.
- Todd, John and Nancy Jack Todd. 1984. Bioshelters, ocean arks, city farming: Ecology as the basis of design. San Francisco: Sierra Club Books.
- Torrance, E. P. and Z. L. Rockenstein. 1988. Styles of thinking and creativity. Learning strategies and learning styles, Editor Ronald Schmeck, 275-90. New York: Plenum Press.
- Vrba and Gould. 1986. The hierarchical expansion of sorting and selection: Sorting and selection cannot be equated. Paleobiology 12: 217-28.
- Waddington, C. H. 1977. Tools for thought. London: Jonathan Cape.
- Waldrop, Mitchell M. 1992. Complexity: The emerging science at the edge of order and chaos. New York: Simon & Schuster.
- Wann, David. 1990. Biologic: Environmental protection by design. Boulder: Johnson Books.
- Wilson, Edward O. Mar 27, 1998. Integrated Science and the Coming Century of the Environment. Science 279: 2048-9.
- Wright, Robert. August 28, 1995. The evolution of despair. Time: 32-8.
- Yin, Robert K. 1989. Case study research: Design and methods. second ed. Applied Social Research Methods Series, 5. Newbury Park: Sage Publications.