Evolution of Housing

NIEL SLOB

PhD Researcher | Delft University of Technology

SAMAN MOHAMMADI

PhD Researcher | Delft University of Technology

ROB GERAEDTS

Associate Professor | Delft University of Technology

ABSTRACT

'*Perfection means something is complete and stands still and what stands still doesn't change or evolve and is automatically dead. Everything in the universe changes, evolution implies that the creation is not complete hence the possibility of evolving*' (Osho, 1985).

Our society and economy are constantly changing. Hence the demands and wishes of users changes all the time. As now in China, the Netherlands had a quantitative demand in housing after the Second World War with a lot of booming developments. At the moment we face the consequences of these booming developments. The housing supply doesn't match anymore the changed demand. So if we could do it all over again, we should answer this quantitative demand with a qualitative supply, namely real estate, which carries the capacity to adapt to these constantly changing demands.
Such 'evolving' buildings should be designed to learn hence being able to adapt to changing conditions, integrate development with growth and evolve to survive like organisms do in a mature ecosystem (Biomimicry Life's principles circle, 2010). In this way we don't focus on maximization (most sustainable real estate at deliverance) but on optimization (flexibility offers the capacity to adapt to changes hence becoming more environmental-and user-focused through time).
This paper does focus on patterns from nature (for instance evolve to survive) and their possible value in developing real estate. Analysis using TRIZ (a problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature) shows that there is only 12% similarity between biology and technology in the principles, which solutions to problems illustrate, while technology solves problems largely by manipulating usage of energy, biology uses information and structure, two factors largely ignored by technology (Vincent, 2006 - Biomimetics: its practice and theory). Biomimicry is learning from nature as a model, mentor, and measure and then emulating natural forms, processes, and ecosystems to create more sustainable designs (Benyus, 2002 Biomimicry).
The core idea is that nature has already solved many of the problems we are dealing with: energy, food production, adaptability, climate control, benign chemistry, transportation, collaboration and more.

Keywords:
Biomimicry, Sustainability, Flexibility, Housing, Revitalization, Patterns from nature.

1. INTRODUCTION

In construction industry, we use a number of resources that have grown, like wood for example, but we don't generally create structures that grow or repair themselves. This is perhaps the area in which there is still the largest gap between biology and engineering, simply because none of our buildings are alive in a sense that is comparable with a living organism.

Change is the only constant factor in the universe and to survive these changes organisms have evolved on this planet. These processes of adaptation can be seen as 'systems', and because of their complex nature the term natural complex system is chosen to denote them. For example, homeostasis, coral reef or a human brain can all be characterized as a natural complex system. These systems are from interest because of their adaptive ability to the constantly changing environment. In spite of their beneficial properties, these systems are still not fully understood.

If we look at current structures, it is clear that they do not have the adaptive properties of natural complex systems. So why don't we create structures in the way nature creates complex systems? By structures we mean buildings, part of buildings, group of parts where the parts on any way show formal, functional or temporal consistency.

As this field of research is relatively new and available knowledge regarding the objective is limited, the nature of the research will be exploratory, intended to generate insights into the applicability of natural complex system inspired design strategies. Because of this at the end we will do a open proposition for a new international research department under CIB, Open Building, or a new entity where we can elaborate and do further research on the topic.

2. STATIC SUPPLY

Vacancy, shortage and blockage

At this moment many structures in the Netherlands like offices, churches, warehouses and old industrial buildings are vacant because they no longer meet present requirements. At the end of 2011 more than 7 million square meter office space was vacant. This is a vacancy rate of 14 % of the total office stock in the Netherlands. Several studies forecast the rise of a vacancy rate up to 30 % in 2015 (DTZ, 2011). This phenomenon will lead to more demolition of existing and vacant structures and to a lot of waste of resources. This leads not only to the destruction of capital but it also has a negative environmental effect.

While the office market is characterized by an oversupply, the Dutch housing market is dealing with a shortage. Due to the fact there is a great need for students, starters and elderly dwellings, it is difficult to find appropriate dwellings. According to the Primos Institute (Otter de, 2010), another half million dwellings must be added until 2020.

Many people in the Netherlands are unable to live in the type of home they would like. The quality and quantity of housing stocks often fail to meet the ever-changing demands of users since too few suitable homes are available. As a result, first-time buyers in particular face difficulties finding a home. In addition, many people choose to remain in their existing home for too long until they are successful in finding a suitable home that matches their specific individual wishes. This is leading to a blockage in Dutch housing stocks (Boelhouwer, 2009).

Changing market

Our society and economy are an ever-changing cycle of moment layered upon moment, day after day, and so on. The Dutch housing market is changing rapidly as a result of privatization and declining production. A downward trend in housing production started in many European Union Member States before it did in the Netherlands. Housing occupancy in Europe is falling to 2.2 people per housing unit and the ageing of the population is accelerating rapidly (Thillart van den, 2006). Generally speaking turnover in the maintenance and refurbishment sector is higher than that of new build.

From quantitative to qualitative approach

As now in China, the Netherlands had a quantitative demand in its housing stock after the Second World War (1945). This rapidly led to a huge number of developments. At the moment we face the consequences of these booming developments in the Dutch housing stock. The existing supply doesn't ecstatically and functionally match the changed demand and in most cases transformation is functionally and financially not feasible (Boelhouwer, 2009). So if we could do it all over again, we should answer this quantitative demand with a qualitative supply, namely structures, which carry the capacity to adapt to these constantly changing demands.

3. ADAPTIVE SUPPLY

Uncertain future

The future is uncertain – the present must be adaptable. What we need is to avoid the vacancy of structures. We can avoid this vacancy by designing and constructing adaptable structures that can adapt to rapidly changing user demands (Geraedts, 2011).
Any built environment solution must be adaptable. Structures have to be able to adapt to the ever-changing needs of the users during the whole life cycle. Structures must remain efficient places to live and work to ensure real life-cycle value (Geraedts, 2009). The market demand for multi-purpose structures also asks for structures that can adapt to changing circumstances.
The question here is which strategies within the construction industry do already exist and how do they steer to the design of adaptive structures?

Open Building and Lean Construction

Open Building is a strategic design and construction method that deals with individual client and user-oriented structures that really can adapt in the development phase and in the user phase as well to changing user and market demands. With Open Building it is possible to adjust built environments and buildings to match with changes in social, environmental and technical requirements (Kendall, Teicher, 2000). Nowadays many participants in construction are convinced that it is very important to develop structures and the facilities of structures simultaneously, especially when future adaptability will be an important issue. To assess the future value of structures not only adaptability is an important aspect, also the way a structure could be dismantled, the amount of waste during construction and re-construction play an important role. Structures that have been designed and constructed to adapt to future changes give answers to these trends.
Open Building and Lean Construction are complementary strategies that can work in synergy (Geraedts et al, 2011). In order to grasp their full potential, some elaboration may be helpful. Open Building gives guidelines for forming the product and to a lesser degree the construction process. Lean Construction is the construction equivalent of Lean Production, which in turn is a westernized interpretation of the Japanese TPS, the Toyota Production System (Womack et. al., 1990). The lean mantra is: create value, banish waste.

Costs and benefits

One of the most important barriers of extra investments in the future adaptability of structures is the fact that the party who is investing in the initial costs of a structure in most cases is not the same party that benefits from this investments in the future when he wants to adapt the structure. Yet, when it comes to weighing alternative solutions, the ultimate lifecycle costs are more important than the possible additional investments involved in certain adaptability provisions (Geraedts, 2001). On the other hand, when there were no investments in future adaptability, changes in buildings can be very expensive. It is obvious that adaptability measures that will not lead to extra investments are the most interesting ones. The implementation of these measures will probably meet no opposition in the field of actors concerned.

4. EVOLUTION AS THE MAIN STRATEGY FOR SURVIVAL

A new approach

Despite the wide spread awareness in the Netherlands of the fact that any built environment solution must be adaptable, that structures have to be able to adapt to the ever-changing needs of the users during the whole life cycle, the construction industry has not been able to develop sufficient answers to these questions the last five decades.
Similarly, we can’t change a reality if we remain in the same the same consciousness that made it. The introduction of a total new nature inspired approach could provide new answers
The art of surviving can more specifically be described as the ability of adapting to the environment, but how does an organism adapt within an ecosystem?

Hypothesis

This paper describes the positioning of a PhD research at Delft University of Technology aiming to explore adaptation within natural complex systems. Organisms survive because they adapt to the changing environment. They have evolved strategies for successful

evolution. This implies that something that has evolved a certain constellation should be able to evolve to a new constellation.
Hypostatically we can state that natural complex systems have properties that are desirable in designing, constructing and operating adaptable structures.
The main question here is where adaptability comes from and how it actually operates within a natural complex system?

5. NATURAL COMPLEX SYSTEMS

Background

If we look at current structures, it is clear that they do not have the adaptive properties of natural complex systems. It is clear that they do not possess the adaptive properties, which are so distinctive for natural complex systems.
So why don't we create structures in the way nature creates complex systems?
Evolution provides an explanation for the biological diversity we have on earth. Through the mechanism of natural selection the number of individuals in a given environment is constantly in balance. Where the individuals that are most fit (adapted to the environment) are more likely to be able to reproduce themselves, this is called survival of the fittest. In natural evolution there are two different ways in which variation in individuals is introduced, through reproduction (genetic recombination) and through gene mutation (Darwin, 1859).
This can be translated as the fact that evolution is neutral towards higher or lower complexity. Hence to achieve a complex solution, evolutionary pressure towards higher complexity is needed. Heylighen (1999b) underscores this by saying that a structurally more complex environment requires a more complex set of functions to cope with it. However, complexity is not a goal on its own, in fact the least complex but working solution is desired.
In order to design and use natural complex systems as design strategies, a deeper level of understanding is required, and their properties need to be known. In the next paragraph a random selection of natural complex systems are analysed. Each of these short analyses is written from the point of view of the related disciplines with their own related examples.

Examples of natural complex systems

- *Biology*

The human immune system defends the body from invaders (antigens) such as bacteria or biochemicals; it is an example of a complex system (Holland, 1992; Di Marzo Serugendo, 2003). It consists of large numbers of mobile 'individuals', called antibodies. The task of some of these antibodies is to distinguish between 'self' and 'non-self' antigens. Holland states that the number of possible invaders is so large that there is simply not enough room to store all that information in the immune system. The immune system is nevertheless very successful because it can change or adapt its antibodies as new invaders appear. How this process of adaptation precisely works is not currently known, as it is hard to simulate or model.

- *Animal and insect communities*

Animal and insects communities such as termites, ants and bees have developed sophisticated social structures, which facilitate task division, communication, cooperation, and so on. Remarkable is that individual termites have very limited cognitive capabilities but are, as a collective, capable of solving complex problems. The collective behaviour that emerges is a form of autocatalytic behaviour, i.e. positive feedback, a reinforcing process that causes very rapid convergence (Dorigo et al., 1991). The secreting and sensing of the pheromone trails is essentially a form of indirect communication, called stigmergy (Di Marzo Serugendo, 2003), which results in cooperation in the swarm. It is this interaction that gives rise to an organized community which is capable of exploring, constructing, finding food, and so on, without any individual alone knowing how to perform such a feat.

- *Ecology*

Ecological systems deal with interacting populations of (different) species; examples are populations of predators and prey or a group of bacteria inside an organism. Ecological systems are characterized by 'causal openness', and that they tend to exhibit 'emergent properties', meaning that unexpected things happen even though the system's components are well known. Small events sometimes cause big changes, while big events sometimes cause hardly any change whatsoever. Ecology evolution is a philosophy movement, which understand this oneness and interconnection of all life and its cycles of change and transformation (Naess, 1989).

- *Physics*

In a potentially magnetic material there are tiny magnets, called spins, which have a particular orientation corresponding to the direction of its magnetic field. Generally the spins will point in different directions, cancelling each other out. The random movements of the molecules in the material cause this disorder. The higher the temperature, the more difficult it is for order to emerge. However, when the temperature decreases, the spins will align themselves, pointing in the same direction. This is because spins with different directions repel each other, and spins with the same direction attract each other (van Lon, 2010). Magnetization is a clear case of self-organization (Heylighen, 1999c).

- *Quantum Physics*

During the early 20th century advances in science revealed a place in nature where Newton's laws just don't seem to work: the very small world of the atom. Before then, we simply didn't have the technology to peer into the subatomic world or watch the way particles behave during the birth of star in a distant galaxy. In both realms (the smallest and largest) scientist began to see things that couldn't be explained by traditional physics. A new kind of physics had to be developed with the rules that would explain the exceptions to our everyday world: the things that happen in the realm of quantum physics (Braden, 2007).

- *Psychology*

In his book 'The Society of Mind' Minsky (1988) presents a theory about the workings of the human mind. He envisions minds as consisting of many smaller processes which he calls agents. An agent is only capable of switching things on and off. However, when these agents combine into communities, argues that this leads to intelligence. He introduces a distinction between agents and agencies, where the latter can do all the things agents can do combined. According to his theory, the mind consists of an enormous hierarchy linking agencies together, where each level builds upon the previous. Agencies are groups of cooperating specialists (agents or agencies), which can themselves be part of an even higher-level agency.

- *Economy*

The concept of a free market as is commonly used in capitalism, is a perfect example of a collective system. It is a market with a minimum amount of centralized control; it works through a constantly changing equilibrium between buyers and sellers. Buyers and sellers make decisions based on local information (e.g. their preferences), on a global level the effects of these decisions manifest for example through the stock market or through a surplus or scarcity in a certain good. About the free market, Heylighen (1999c) states that the failure of the communistic system has shown that the market is much more effective at organizing the economy than a centrally controlled system. However, the recent economic crisis has shown that even the free market isn't perfect and that occasional oscillations can arise.

Theories behind natural complex systems

Natural complex systems as discussed in the previous paragraph are investigated from different point of views, from different disciplines, which has resulted in different theories and examples. In this section three main theories behind natural complex systems are elaborated.

- *Complex Adaptive Systems*

Complex Adaptive Systems is a term originally invented by John Holland (1992). He states that there are many different complex adaptive systems; all of them consist of great numbers of simultaneously interacting parts. They share three characteristics: evolution, aggregate behaviour, and anticipation. In complex adaptive systems, it is the parts that evolve in a Darwinian fashion, each trying to survive in their interactions with the surrounding parts. This evolution can be called adaptation or learning. Aggregate behaviour is the notion of globally observed behaviour, which can be said to emerge from the interactions of the parts. Anticipation can be thought of as the parts that are developing rules that anticipate the consequences of certain responses. Because the parts are conditioned in different ways and depend on the interactions between the parts, the consequential anticipation can cause major changes in aggregate behaviour. John Holland notes that anticipation is the feature that we least understand but that is one of most importance (Holland, 1992).

The systems basic components can be seen as sets of rules; they rely on three key mechanisms: parallelism, competition, and recombination.

- Parallelism allows the system to use individual rules as building blocks, it can activate sets of rules simultaneously.
- Competition provides the adaptation necessary to operate in realistic environments where the agent receives a stream of (mostly) irrelevant information. Using credit assignment for rules and rule discovery procedures, useful events are recognized from this stream of information and are used as building blocks in new, similar contexts.
- Recombination facilitates the discovery of new rules from parts of successful tested rules.

These procedures give the system its characteristic evolving structure; it continuously tries to improve its own performance (Holland, 1992).

- *Collective Intelligence*

Collective intelligence is defined as the ability of a group to solve more problems than its individual members (Heylighen, 1999a). The system properties can be divided in two categories namely: (Martijn Schut, 2010):

- The enabling properties (or the requirements), which indicate that if they are present, it is possible for Collective Intelligence to emerge.
- The defining properties (or the success parameters, which indicate whether the system was correctly constructed), which if observed indicate that the system is a collective intelligence system.

- *Swarm Intelligence*

Swarm intelligence is the emergent collective intelligence of groups of simple agents
(Kennedy et al, 2001).

Swarm Intelligence is inspired by phenomenons like the bird flocking, fish schooling, and so on. These are system wherein agents following simple rules. Again is swarm intelligence closely related to the Collective Intelligence and complex adaptive systems.

Properties of natural complex systems

The theories and examples presented in the previous paragraph have shown that there are many different views on natural complex systems. But when we consider these theories and examples together, something no less than a paradigm shattering happens: They begin to tell us a story. Based on the similarities within these theories the following definition of natural complex systems is proposed:

Natural complex systems are adaptive systems composed of emergent and self-organizing structures.

Uny Cao et al. (1997) state that complex systems are often described using emergence and self-organization as the most important properties of a complex system. This can also be concluded out of the description of theories behind natural complex system in the previous paragraph where these two properties are apparent. These properties were chosen since all other relevant properties can be derived from these two, in fact, it could be said that self-organization itself is often an emergent property. This positions self-organization and emergence as the most important features for generating adaptive behaviour. Because emergence and self-organization are itself complex concepts, they will be explained in detail in this paragraph.

- *Main property 1: Emergence*

In (Corning, 2002) it is stated that there is no universally acknowledged definition of emergence; however, he states that the most elaborate definition is: emergence is the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems.

Self-organization and emergence are difficult to tell apart. But Schut (2010) gives a more simple definition namely: “the whole is more than the sum of its parts”. A result of this lack of a proper definition is that there is a lot of controversy how emergent properties are to be distinguished from non-emergent properties (Damper, 2000). Nevertheless, there have been made many attempts in the literature to define different types of emergence and to give a list of properties. In this paragraph three typical properties are listed which are needed to attain emergence.

- Local & Global
This distinction can be generalized with the concepts of aggregates; for example, phenomena and natural laws at a given level emerge from the operation of laws at a more fundamental level (Damper, 2000).
- Interaction
An example of the interaction effect is the cooperation between multiple entities, for example in a termite colony.
- Non-linearity
Non-linearity can be explained by the (chaotic) butterfly effect, which says that small causes can have large effects, and large causes can have small effects.

- *Main property 2: Self-organization*

The most stunning thing living systems and social systems can do is to change themselves utterly by creating whole new structures and behaviours. In biological systems that power is called evolution. In human society it's called technical advance or social revolution. In systems lingo, it's called self-organization (Meadows, 1999).

As with the concept of emergence, there is no generally acknowledged definition for self-organization. De Wolf and Holvoet (2005) has provided an intuitive definition of self-organization namely: self-organization refers to exactly what is suggested: systems that appear to organize themselves without external direction, manipulation, or control.
Di Marzo Serugendo, (2003) provided a most elaborate definition which joins self-organization and emergence together: self-organizing systems are made of many interconnected parts whose local interactions, within a given environment, give rise to emergent properties, or behaviour, observable at the level of the global system only.

In this paragraph three typical properties that can be associated but are not exclusively related to self-organization are listed. These properties are needed to attain self-organization.
- Decentralisation
Decentralization means that there is no central controller that supervises all the parts. In fact, all individuals are autonomous, meaning that they are self-governing; however, this doesn't mean that they don't influence each other, they interact.

- Feedback
Each component in a system affects the other components, but these components in turn affect the first component. As a result there exists a circular cause-and-effect relation called feedback (Heylighen, 1999c). Feedback can be categorized in to parts namely: positive (self-reinforcing) feedback allowing deviation to enlarge in an explosive way, and negative (self-counteracting) feedback that stabilizes the system (van Lon, 2010).
- Randomness
Randomness can be defined as followed: adaptation in nature is almost always a stochastic process, meaning that it contains randomness. The first reason is that it is an expression of uncertainty, if you don't know where to go; a random direction is as good as any. Second reason that they provide is, by trying something new, randomness introduces creativity or innovation, which can lead to a self-organized system (Kennedy et al., 2001).

- *Adaptation as a result of emergence and self-organisation*

In biology, adaptation is the process whereby an organism fits itself to its environment (Holland, 1995). In the sense that we use it here, the system takes the place of the organism and the environment is defined by the system's input and output. De Wolf and Holvoet (2005) state that to be adaptable, a system needs to make a selection between behaviours and at the same time consider a variety of behaviours. This is a balance, where an abundance of variety makes the system uncontrollable, and too much selection yields in a system that is not adaptable enough. It is stated by Heylighen (1999c) that in a sense, self-organization implies adaptation.
In this paragraph the underlying rules of adaptation are described as a result out of the two properties of both self-organization and emergence. Through these properties, adaptation is linked to complex systems in general.

- Anticipation
Anticipation or prediction can be thought of as developing rules that anticipate the consequences of certain responses. Internal models are introduced in as a means to anticipate future events (Holland, 1995). Models are abstractions of the real world. They are a very useful construct that allows reasoning about the world. Key here is the

specific design of this structure; this is what really makes anticipation possible.

- Autocatalysis

The concept of autocatalysis originally comes from chemistry; a catalyst is a substance that enables a chemical reaction. In autocatalysis the catalyst is one of the products of the reaction, thereby enabling itself. An autocatalytic set is a set of reactions that are not individually autocatalytic, but who catalyse each other. It also allows the system to deviate from one stable state to another state; it can be triggered by (external) circumstances to which the system needs to adapt itself (Parunak and Brueckner, 2004).

- Resilience

Resilience refers to the adaptability of a system; it is the capacity to restore itself (Heylighen, 1999c). For instance, if a coral reef is damaged by fluctuations in sea temperature it is in general able to restore itself.

- Robustness

Robust systems are relatively insensitive to perturbations or errors and have a high fault-tolerance (Heylighen, 1999c). A robust system is expected to deal with continuous change and to maintain its organization autonomously (De Wolf and Holvoet, 2005).

- Redundancy

A system is redundant when it has the same knowledge represented in a number of different places (Schut, 2010). Knowledge is nonlocal and holographic. Every part of it is connected to every other, and each piece mirrors the whole on a smaller scale. This is a kind of robustness as a system shows a certain insensitivity to damage due to replication of components (Di Marzo Serugendo et al., 2006). The failure of a single entity will not cause a complete failure; the system is flexible enough such that the emergent structure can remain (De Wolf and Holvoet, 2005).

The question that arises here is, whether there exist designing strategies that use adaptation as an inspiration and how we can intervene in existing systems to implement these strategies successfully?

6. NATURAL COMPLEX SYSTEMS INSPIRED DESIGN STRATEGIES

To design a usable complex system it takes a lot of effort. The most difficult part is how to make the complex system in a way that it is beneficial. The difficulty of creating such systems lies in the mimicking of the properties, which we have explained in the previous chapter. Changing or designing a local component can yield unforeseen global system behaviour; this is an effect of a complex system's inherent non-linearity and randomness. Holland (1998) states that when parts interact in less simple ways, reduction does not work, both the interactions as well the parts have to be studied. By analogy, this means that when designing a complex system, the local components, the local interactions, and the global perspective all need to be taken into account.

In this chapter existing design strategies inspired by natural complex systems will be described which can be useful for developing adaptive structures.

Existing design strategies

Out of the 30 approaches described by AIGA, six approaches (The Hannover Principles, IDSA Eco Design Principles and Practices, The Natural Step, Biomimicry, Natural Capitalism and Cradle to Cradle) make reference to 'nature' or the natural world (de Pauw et al., 2010). Four of the six approaches (The Hannover Principles, Biomimicry, Natural Capitalism and Cradle to Cradle) refer directly to nature as a model, something to emulate, an inspiration, a mentor, an example or as a goal. The last criterion for the selection addresses the applicability of the approaches for sustainable product development. The approaches that have already been applied in this field have been selected. McDonough and Braungart have developed both the Hannover Principles and Cradle to Cradle. Comparing these two strategies, Cradle to Cradle has specifically been developed for sustainable product development, whereas the Hannover Principles provides a set of principles written for designing the built environment (McDonough, 1992). Therefore the Hannover Principles is not included as a separate strategy. To sum up, the following natural complex system inspired design strategies are described in this chapter:

1. Biomimicry
2. Natural Capitalism
3. Cradle to Cradle

1. Biomimicry

'Biomimesis', 'Biomimicry', 'bionics', 'biognosis', 'biologically inspired design' and similar words and phrases implying copying or adaptation or derivation from biology. From al these strategies Biomimicry and Biomimetics are currently providing the most innovative solution. This is a relatively young study embracing the practical use of mechanisms and functions of biological science in engineering, design, chemistry, electronics, and so on. However, people have looked to nature for inspiration for more than 3000 years. Biomimicry literally means the imitation of life.

As the 'design languages' in biology and engineering differ greatly, several researchers are working on methods and databases to facilitate the transfer of knowledge from biology to design and engineering (Sarkan et al., 2008, Stroble et al., 2009). Research is being carried out on identifying more general design principles from the field of biology, ecology and other natural complex systems (Bowyer et al., 2003, Winters, 2009, Reap et al., 2005). During this research the Biomimicry Institute has developed the 'Life's principles' (Biomimicry-Institute, 2010) and the University of Bath developed 'BioTRIZ' (Vincent et al., 2006).

The first level of Biomimicry is the mimicking of natural form. Deeper Biomimicry adds a second level, which is the mimicking of natural process, or how it is made. At the third level is the mimicking of natural ecosystems.

The goal is to create products, processes, and policies - new ways of living - that are well adapted to life on earth over the long haul.

The following options are provided for integrating biology into design (Biomimicry Guild, 2010):

- In scoping: (re)defining the design problem.
- In idea-generation: retrieving inspiration and engineering solutions from nature.
- In engineering and evaluation: guidelines and (sustainability) criteria for product engineering.

Their 'Design Spiral' gives a method for applying Biomimicry in the design process. Beside Biomimicry the strategy of Biomimetics has developed a tool to enable the creation of a complex system. Biomimetics, a name coined by Otto Schmitt in the 1950s for the transfer of ideas and analogues from biology to technology, has produced some significant and successful devices and concepts in the past 50 years, but is still empirical. TRIZ, the Russian system of problem solving, has shown that it can adapt to illuminate and manipulate this process of transfer. Analysis using TRIZ shows that there is only 12% similarity between biology and technology in the principles which solutions to problems illustrate, and while technology solves problems largely by manipulating usage of energy, biology uses information and structure, two factors largely ignored by technology (Vincent et al., 2006).

2. Natural Capitalism

The basic driver for Natural Capitalism is that "In the next Industrial Revolution – already under way - we will have abundant people and scarce nature, not the other way around. So it now makes sense to use nature far more productively" (Lovins, 2001).

To achieve natural capitalism, four major shifts in business practices are proposed (Hawken et al., 1999, Rocky-Mountain-Institute, 2010):

- Radically increase the productivity of natural resources.
- Shift to biologically inspired production models and materials
- Move to a "Service-and-Flow" business model
- Reinvest in natural capital.

The strategy seems to include Biomimicry and Cradle to Cradle in their approach. Natural Capitalism Solution, an organization founded by Hunter Lovins, directly refers to the use of Biomimicry and Cradle to Cradle as approaches for meeting their second principle to 'redesign as nature does' (NaturalCapitalismSolutions, 2010).

3. Cradle to Cradle

Cradle-to-Cradle (C2C) is a phrase invented by Stahel in the 1970s and popularized by McDonough and Braungart in 2002 in their book of the same name. It is an alternative for the well-known phrase 'Cradle to Grave', which refers to taking into account all effects of a product during its entire lifecycle from production to disposal. C2C identifies three key tenets in the intelligence of natural systems that can inform human design:

- Waste equals food; using closed-loop material systems.
- Use current solar income; C2C systems could directly collect solar energy or tap into passive solar processes
- Celebrate diversity; tailoring designs, drawing information from local natural systems and ultimately “fit” within these systems.
(McDonough et al., 2003).

7. EVOLUTION IN PRACTICE

As mentioned in the previous sections the natural complex system inspired strategies seem predominantly resources and technology oriented. However, several design principles do relate to the way people use products and interact with the product-system. Natural complex systems have two main properties namely self-organization and emergence. A system with these properties has the ability to adapt and the underlying rules of adaptivity we have used to illustrate our projects in practice.
We are testing these nature-inspired design strategies and in general the properties of natural complex system, in practice by our advisory and project-management office draaijer+partners in several projects namely:
- A new building for Mental Health Institution Dimence Almelo, the Netherlands
- An expansion for the International School of Amsterdam (ISA), the Netherlands
- The optimization of a building for Healthcare Group Reinalda Amstelveen, the Netherlands

Mental Health Institution Dimence
In this project a slight attempt is made to create Anticipation and Robustness. Anticipation introduced models as a means to anticipate future events. Robustness is expected to deal with continuous change and to maintain its organization autonomously.
This first project consists of 12,500 m2 GFA for the new Mental Health Institution Dimence. In this project the base structure (support), and fit-out (infill) are separately programmed, designed and will be realized. The support consists of the main structure, facades and main installations. The infill consists of the inner walls, interior and secondary installations. All of these layers can be demounted in small components that can be reused or optimized. To respond to the changing market demand, the total volume of the structure will be developed such that it is dividable into four self-operation unities, which on their part can function as a whole. This provides a high ability of anticipation on future events. The robustness of the structure lies in the fact that if the user demand changes, the building, part of the building or group of parts can be optimized to again fulfil the demand or they can be used for other purposes. Finally it can be demounted without the wastage of high quality raw materials and the ground can be used for other purposes. We will keep monitoring, analysing and optimize the use during the exploitation phase.

International School of Amsterdam
In this project again a slight attempt is made to create robustness. Robustness is expected to deal with continuous change and to maintain its organization autonomously.
To steer on robustness in this project the producers of (cradle to cradle) floors, lighting and furniture maintain the right to their own products. They only carry over the assembled whole and will be confronted with the minimal claim that they need to maintain their own product in the form of services in time. This implies that, if the producers are able to install their product on a more economical or sustainable way, they should be allowed to do so. Provided that, the user and other related parties agrees upon this change and its impact; the producer bears the total costs and the new product provides at least the same ability as its predecessor. On the contrary, if the producers innovate and the user wants their new products, the product should carry the ability to exchange its components with the same or other producers in the field. In this way we are trying to shift the innovation and sustainability to the producer hence coming to a higher level of robustness.

Healthcare Group Reinalda
In this project a slight attempt is made to create resilience and redundancy. Resilience refers to the adaptability of a system; it is the capacity to restore itself. Redundancy is when

the same knowledge represented in a number of different places.
In this project a top down analyses provided strategically areas within the existing structure, which needed to be measured for optimization. According to these results wireless sensors are installed to measure the energy use and occupancy rate through the summer and winter period. These results should provide answers how to revitalize the existing structure.
When connecting these wireless sensors to the Building Information Modelling (BIM) during the design and realization phase and then to the building control system during period of use they can provide sufficient information for resilience. This system can operate as a kind of structure's consciousness in the form of redundancy. On the contrary, resiliency can only take place if according to the measurements, a new product, installation-system, function, and so on, is able to be installed within the (existing) structure which should carry the ability to (manually or automatically) adapt to these changes.

Next step in the evolution of constructing
Of course, one of the key differences between biological structures, such as trees, and human-made buildings is that buildings don't move. In fact, most of the time we actively want to reduce the amount of the things that move so that people feel safe and less inclined to revisit their lunch. The consequence of this is that the amounts of material used in our structures can look extremely inelegant compared to the more plant forms found in nature. Besides that in construction industry, we use a number of resources that we have grown, like wood for example, but we do not generally create structures that grow or repair themselves. This is perhaps the area in which there is still the largest gap between biology and engineering, simply because none of our buildings are 'alive' in a sense that is comparable with a living organism. We are likely to see structures evolving into complex systems that increasingly resemble living organisms. The direction in which we need to be heading is towards structures that are extended organisms, where function and structure melt together, and are controlled by the overriding demands of homeostasis and an underlying consciousness.

8. CONCLUSIONS

Hypothesis
In chapter 4 we stated the following hypothesis as the foundation of this paper:
Natural complex systems have properties that are desirable in designing, constructing and operating adaptable structures.

To answer this hypothesis in chapter 5 we firstly described some examples and theories to come to the properties of natural complex systems. These properties were based on emergence (with three typical properties namely; local & global, interaction and non-linearity) and self-organization (with three typical properties namely; decentralization, feedback and randomness). The result of emergence and self-organization is adaptation (with five underlying rules; anticipation, autocatalysis, resilience, robustness and redundancy). These are all highly desirable properties for structures, as such; natural complex systems provide a promising alternative strategy for structures.
These properties are particularly suited for the always-changing environment and therefore required adaptivity. And as was stated in chapter 2, traditional way of constructing lacks these adaptive properties. However, the design of complex systems is hard; their emergent properties are difficult to steer in a preferred direction.
Next an analysis was provided of the currently existing natural complex system inspired design strategies in chapter 6. To sum up, the following strategies are suited for designing complex system when using evolution as a basic rule: Biomimicry, Natural Capitalism and Cradle-to-Cradle.
These existing strategies can help producers, assemblers, users and financiers design, construct and operating adaptable structures. Although promising and inspiring, the strategies seem not yet to offer a clear and tested approach on how to apply the strategies and their design principles to support designing, constructing and operating adaptable structures. The existing strategies

seem predominantly resource and technology oriented. Because of this in chapter 7 we have used the main properties of a natural complex system for our projects in practice as discussed in chapter 5, these were the following projects:
- A new building for Mental Health Institution Dimence Almelo, The Netherlands
- An expansion for the International School of Amsterdam (ISA), The Netherlands
- The optimization of a building for Healthcare Group Reinalda Amstelveen, The Netherlands

At the end we stated that we are likely to see structures evolving into complex systems that increasingly resemble living organisms. The direction in which we need to be heading is towards buildings that are extended organisms, where function and structure melt together, and are controlled by the overriding demands of homeostasis and an underlying consciousness.

Evolution of Housing & Long Lasting Buildings in China

China currently faces a huge demand in its housing stock, which can rapidly lead to a quantitative development of (low quality) housing for the short term. As mentioned in chapter 2 in the Netherlands we have made this mistake after the Second World War and currently face the consequences of these booming developments in the our housing stock. The existing supply doesn't ecstatically and functionally match the changed demand and revitalization is functionally and financially not feasible.

China should answer this quantitative demand with a qualitative supply, namely structures, which carry the capacity to adapt to the constantly changing demands of its users and market hence optimizing their quality through their life cycle. Newly complex system inspired design strategies can help producers, assemblers, users and financiers design, construct and operate adaptable structures. Being inspired by nature requires understanding how nature 'works'. The knowledge that has been published so far does provide insights that seem to back-up existing principles and adds principles that are novel to the development of adaptive structures.

Recommendation

Because of this we would like to do an open proposition for a new international research department under CIB, Open Building, or a new entity where we can elaborate and do further research on the topic of self-organizing and emergent structures. This can help us to find new ways to create structures that are celebratory as well as being radically more like natural complex systems and utterly in harmony with nature.

LITERATURE

- Boelhouwer, P. (2009). Towards a Better Balance on the Dutch Housing Market? TU Delft, Netherlands.
- Bowyer, A., Vincent, J. F. V., Bogatyreva, O. and Pahl, A.-K. (2003) Data Gathering for Putting Biology in Triz. Altshuller Institute, USA.
- Braden, C. (2007). The Divine Matrix. Hay House, Australia.
- Braungart, M., McDonough, W. & Bollinger, A. (2007) Cradle-to-cradle design. Journal of Cleaner Production, 15, 1337-1348.
- Corning, P. A. (2002). The re-emergence of "emergence": a venerable concept in search of a theory. Complexity, 7(6):18–30.
- Damper, R. (2000). Emergence and levels of abstraction. International Journal of Systems Science, 31(7):811–818.
- De Pauw, I. , Kandachar, P., Karana, E., Peck, D., Wever, T. (2010). Nature inspired design. TU Delft, The Netherlands.
- De Wolf, T. and Holvoet, T. (2005). Emergence Versus Self-organisation. Engineering Self Organising Systems, 3464:1– 15.
- Di Marzo Serugendo, G. (2003). Engineering Emergent Behaviour: A Vision. In Hales, D., editor, Multi-Agent-Based Simulation III, pages 1–7, Berlin Heidelberg. Springer-Verlag.
- Di Marzo Serugendo, G., Gleizes, M.-P., and Karageorgos, A. (2006). Self-organization in multi-agent systems. The Knowledge Engineering Review, 20(02):165.
- Dorigo, M. and Socha, K. (2006). An Introduction to Ant Colony Optimization. DSCUA. Delft.
- DTZ Zadelhoff (2011). Nederland compleet, factsheets, Amsterdam, The Netherlands
- Geraedts, R.P. (2001) Costs & Benefits of Flexibility. In proceedings of the CIB World Building Congress, Wellington, New Zealand.
- Geraedts, R.P. (2009) Future value of buildings, SASBE2009. Delft, The Netherlands
- Geraedts, R.P. Cuperus, Y., Shing, K. (2011) Timeless Flexible Building, International A4D Conference, Boston USA.
- Hawken, P., Lovins, A. and Lovins, L. (1999) Natural Capitalism: Creating the next industrial revolution, Boston, Little, Brown and Company.

- Heylighen, F. (1999a). Collective Intelligence and its Implementation on the Web; Computational Mathematical Organization Theory, 3:253–280.
- Heylighen, F. (1999b). The growth of structural and functional complexity during evolution. Dordrecht. Kluwer Academic.
- Holland, J. H. (1992). Complex Adaptive Systems. Daedalus, 121(1, A New Era in Computation):17–30.
- Holland, J. H. (1995). Hidden Order. Perseus Books, New York.
- Holland, J. H. (1998). Emergence: From Chaos To Order. Perseus Books, New York.
- Kendall, S., Teicher, J. 2000, Residential Open Building, E & FN Spon.
- Kennedy, J., Eberhart, R. C., and Shi, Y. (2001). Swarm Intelligence. Morgan Kaufmann.
- Lovins, A. (2001) Natural Capitalism. Available at: <http://www.abc.net.au/science/slab/natcap/default.htm> [Accessed 28 August 2010].
- McDonough, W. (1992) The Hannover Principles. Charlottesville.
- McDonough, W. and Braungart, M. (2002) Cradle to cradle: Remaking the way we make things, New York, North Point Press.
- McDonough, W., Braungart, M., Anastas, P. T. and Zimmerman, J. B. (2003) Applying the Principles of Green Engineering to Cradle-to-Cradle Design. Environm. Science & Technology, 37, 434A-441A.
- Naess, A. (1989) Ecology, Community and Lifestyle. Cambridge University Press. Cambridge.
- Otter, H.J. de, et al (2010). Primos prognose 2009, De toekomstige onwikkeling van bevolking, huishoudens en woninbehoefte, Delft, ABF Research.
- Parunak, H. V. D. and Brueckner, S. A. (2004). Engineering swarming systems. Methodologies and Software Engineering for Agent Systems, pages 1–29.
- Reap, J., Baumeister, D. & Bras, B. (2005) Holism, Biomimicry and Sustainable Engineering. ASME Conference Proceedings, 2005, 423-431.
- Rocky-Mountain-Institute (2010). Natural Capitalism, [online] Available at: <http://www.rmi.org/rmi/Natural++Capitalism> [Accessed 17 August 2010].
- Sarkan, P., Phaneendra, S. and Charkrabarti, A. (2008) Developing Engineering Products Using Inspiration From Nature. Journal of Computing and Information Science in Engineering, 8, 031001-9.
- Schut, M. C. (2010). On model design for simulation of collective intelligence. Information Sciences, 180(1):132–155.
- Stroble, J. K., Stone, R. B., McAdams, D. A. and Watkins, S. E. (2009) An Engineering-to- Biology Thesaurus To Promote Better Collaboration, Creativity and Discovery. Cranfield University Press.
- Thillart van den, C., (2006) Mass Customization concepts and networks for the European market. Adaptables TU/e, Eindhoven, The Netherlands.
- Uny Cao, Y., Fukunaga, A. S., and Kahng, A. B. (1997). Cooperative Mobile Robotics: Antecedentsand Directions. Autonomous Robots, 4:7–27.
- Vincent, J. F. V., Bogatyreva, O., Bogatyrev N., Bowyer, A. and Pahl, A. (2006). Biomimetics: its practice and theory. Journal of the Royal Society Interface. University of Bath, Bath.
- Winters, J. (2009) Learning from nature. Mechanical engineering. New York, The American Society of Mechanical Engineers International, [online] Available at: <http://memagazine.asme.org/Articles/2009/July/InputOutputM.cfm> [Accessed 30 August 2010].
- Womack, J. P., D. T. Jones, et al. (1990) The Machine that Changed the World, New York, Harper Perennial, USA.