A ‘Natural’ Approach to Design

Damian Rogers, Filippo A. Salustri

PhD Student, Ryerson University: *damian.rogers@ryerson.ca*

Associate Professor, Ryerson University: *salustri@ryerson.ca*

Abstract: Current design processes are all generally similar in approach, but none yet address sustainability directly. When sustainable design is pursued, bio-inspired design or biomimicry are invariably used. These approaches attempt to reuse principles found in nature to conceptualize artifact designs. However, sustainable design approaches have yet to be integrated into typical design processes as they occur in practice; these methods generally work by seeking solutions only on a case-by-case basis. As a result, sustainable design methods like biomimicry tend to be used as ancillary or "after the fact" techniques. To fully integrate sustainability into design processes, the authors believe we must look more deeply at the processes that occur in nature and that have led to the organisms often referred to in biomimicry and related methods.

The authors’ study of natural evolutionary processes has led them to believe that there is significant similarity in the way successive generations of artifacts and organisms change. We found that we could describe processes in generic terms that applied equally well to natural evolution and the way that artifacts change over time: that is to say, we found an analogy between generational changes in artifacts and in organisms. The authors are now delving into more detail, and are finding that the analogy can extend to cover natural selection, mutation, and genetic structures. A detailed explanation of this analogy, working at several different levels, is given in this paper. Furthermore, natural and artificial lifecycle processes are shown to be nearly identical.

Since the analogy appears to hold well at many levels of detail, the authors propose to create a genetic structure (a genome) for artifacts. We contend that such a structure would be useful for designers. For example, we find that using the structure of the analogy as a guide can help reduce complexity of design problems. Also, we show that the artificial “genes” lend themselves to description via pattern languages, which are also known to reduce problem complexity. We hypothesize that using pattern languages to represent an artificial genome for designed artifacts will result in a useful, more holistic approach to sustainable design - one that is literally inspired by nature.

Keywords: Analogy, DNA, evolution, design process, product design, sustainability

1. Introduction

Design problems are becoming more complex as civilization advances. This increased complexity requires designers to consider ever more factors. However, there is a limit to the number of factors the human mind can consider simultaneously [10]. This is to say that there are some cognitive limits on the ability to understand a problem in its entirety and this limits the ability to design a proper solution “from scratch.”

While mathematics and logic have ways of breaking down problems into more manageable pieces, there is at present no corresponding way to simplify complex design problems [1]. Considering these two issues together, it becomes clear that designers require tools with which to simplify the complex problems into more manageable portions that go beyond conventional mathematical/logical analysis.

It is here that an analogy is useful [6]: it can provide to designers a way to break down complex design problems as well as a means to find potential solutions. Along with the usefulness of an analogy-based design process, using pattern languages to build the analogy will also reduce complexity. Since patterns have been shown to reduce problem complexity in a variety of differing areas of design, as well as other disciplines, then it follows that using patterns to build an analogy can greatly reduce complexity in design problems [2].

Patterns, as first described by Alexander et al [2], can be thought of as recipes to create a specific artifact. A pattern describes a process, method, or activity related to creating the artifact that it describes. It is usually the case that a pattern pertains to a *best practice* of sorts. This is due to the fact that most industries tend to "throw away the book" as it were and use the knowledge and experience of those in positions of seniority when creating the artifacts. This is exactly the sort of behaviour that this paper focuses on curbing, in the hope that using more structured approaches to design will enhance the fitness and sustainability of the artifacts produced.

Pattern languages are then the culmination of patterns, inter-connected to provide greater meaning or to create a more complex artifact. Much like single words are connected through grammatical relations to make sentences and further, a communicable language, patterns are linked through certain relations to create a pattern language.

If the analogy were also to draw on natural, biomimetic, or sustainable design principles, one can expect a more ubiquitous presence of environmental consciousness embedded in the resulting design processes.

It occurred to the authors while discussing the role of drawings with colleagues in architecture that a certain similarity existed between design as an element of technological progress and the global ecosystem, and natural evolutionary processes. As we continued to explore this striking similarity, it became apparent that one could draw a fairly strict analogy between these two phenomena. From this we reasoned that it should be possible to describe a *genetic code* for engineered artifacts, and to use principles of genetic engineering, drawn through our analogy, to suggest new design methods that could more fully account for the impact of designs on the global environment, not only ecologically, but economically, culturally, and technologically as well.

All of this work rests on the robustness of the analogy between designing and evolution. Thus, the research question we address in this paper is: Is it possible to develop a robust and sensible analogy between designing and evolution? As we will show in this paper, we believe the answer to this question is *yes*. We proceed by first outlining the current state of design as described in the research literature. We then give a general explanation of the major features of natural evolution. We then begin to draw the analogy between the two phenomena in stages, including a proposal for a genetic structure of designed artifacts. Finally, we consider how practicing designers could use such a genetic code to develop new product concepts.

2. Current State of Design

Currently, there are many different processes for designing products. All of these processes include very similar high-level tasks that are executed throughout the design process. These high level tasks include: understanding the design problem; conceptualizing possible solutions; generating many alternative solutions; selecting a best solution of greatest "fitness"; and detailing and optimizing that solution as required.

Let us focus for a moment on the concept selection task, of which two key aspects are (a) the method used to compare concepts and (b) the reference against which those comparisons are made.

Many researchers (Terninko [15], Pahl & Beitz [11], Dieter [5], Suh [14], Ullman [17] and others) have noted that design concepts must be compared to some similar or related product that already exists. This essentially ensures a fixed "origin" for the scale used to measure design concept fitness. Selection of such a product would be based in part on the "success" of particular products on the market. This suggests, and the authors assume it in this paper, that new designs are thereby partly reflective of previous designs. Furthermore, we suggest that a population of products undergoing such generational change over time undergoes a sort of *evolution*.

It is not surprising that, quite similarly, nature does the same thing in creating new kinds of organisms; it references an environment in which the organism is to be placed (understanding the problem), has many variations of genetic options available (different conceptual solutions) from which to choose an appropriate combination of genetic material (selecting a best solution) that will fit well within the environment and evolve continuously to increase its fitness with that environment (detailing and optimization).

Furthermore, the way that "successful" design solutions are identified (by users, the market, and society) is similar to natural selection (i.e. designers choose concepts that will ideally be superior to extant products on the market, much like in nature where successive generations are better suited to their natural environment). Indeed, once the product is in the market, its success or failure depends on its fitness with that changing environment (ecology, market, economics, social preferences, etc). Products that fail are not necessarily bad products; they are just bad products *for that environment*. Because of these similarities, we propose that, like natural organisms, designs also *evolve* over time and as new artifacts are created.

It is difficult to talk about a design approach that is analogous to nature's own way without also talking about sustainability. The natural ecosystems of organisms evolve themselves to seek an equilibrium that tends to result in long-term viability of all of the ecosystem elements – this is one way to define *sustainability*. Herein lies an opportunity: if we can map the kind of equilibrium exhibited by natural systems into the artificial ecosystem of designed artifacts in society, then we may be able to more directly embed sustainability into the artificial environment constructed through a design process, using the same type of mapping; *a genome*. Therefore, to fully integrate sustainability into design processes, the authors believe we must look more deeply at natural processes that have led to the organisms often referred to in biomimicry and related methods.

3. Evolution of Designs and Artifacts

What do the authors mean when we speak of the *evolution* of a design? As mentioned above, evolving products can be likened to naturally evolving organisms: new designs always have a previous entity on which they are based. This allows the new design to potentially be more fit in the extant environment. A few examples include: the PDA evolved from the leather-bound agenda [3], 3G mobile phones evolved from their 2G predecessors, the automobile evolved from the horse-drawn carriage, and space launch vehicles evolved from missiles.

Therefore, the evolution of artifacts takes place on the large scale and not simply only within a design process. Indeed, when the authors write of evolution, we wish to convey that it is a course of action that occurs over many cycles of a product's lifetime, or even over many generations of an artifact type. One can think of two distinct *loops* of design: one occurring on a small scale over the course of the design process itself and thus encapsulating the process of designing a single artifact (which is shown in other literature to occur over many iterations of the process steps); and a second loop occurring at a large scale, over generations of products as they are designed, made, used, and impacted by the context of their lifecycle and thus influence successive generations.

The analogy becomes quite interesting in this large-scale, evolutionary loop; this is our focus in this paper. We can see here that a set of artifacts can act quite like naturally evolving, living things. A product is designed in the smaller design process loop, after which it is brought to market and impacts and is impacted by its environmental context. In this context, certain aspects of the product may be liked or disliked by the users and those features then perpetuate and influence the next product, which is again designed in the smaller loop of the design process. This large evolutionary loop, with its encapsulated smaller design loop, can be visualized in the graphic below.

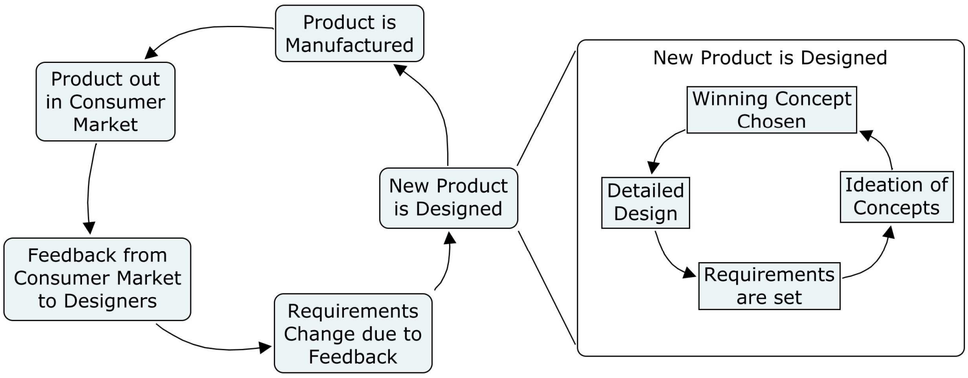

Figure 1. Evolutionary Lifecycle of a Product

Also of note in this figure is that the “feedback” seen in the evolutionary loop is not simply just consumer feedback from users, but also, sales information, warranty returns, media hype, etc.

3.1 Comparing Biological and Artificial Phenomena and Processes

In this section, the authors outline the elements of our proposed analogy, by describing each element in terms of natural evolution, and then rewriting the description in terms of the evolution of designed artifacts. We do this to emphasize the similarities between the two phenomena. We begin with an overview of evolution as a process.

Description of Biological Evolution: Natural evolution proceeds on two oppositional processes: mutation and interbreeding, which increases genetic diversity; and natural selection, which decreases genetic diversity. Mutation and interbreeding cause new genetic variations that render as new physical characteristics. These characteristics manifest new behaviours by which organisms can interact with their environment. Natural selection is the bias shown to organisms whose behaviours allow them to reproduce successfully. If a given genetic change induces a characteristic that enables behaviour in a given environment that allows an organism to reproduce better/faster, then over time that genetic change will become dominant and the organism is said to evolve.

Description of Artificial Evolution: Given a population of artifacts, evolution proceeds based on two oppositional processes: mutation and interbreeding, which increases “genetic” diversity; and *anthropogenic selection*, which decreases “genetic” diversity. Mutation and interbreeding cause new variations in designs, that render as new physical product characteristics. These characteristics manifest as new artifact behaviours/performances in successive generations to fit the environment. Anthropogenic selection is the impact that those behaviours have on the ability of the artifacts to last long enough to be become successful in the market. If a given genetic (design) change induces a product characteristic that leads to a behaviour in a given environment and allows an artifact to succeed in a market, then over time that change will become dominant in the overall population of artifacts. This is anthropogenic selection. Two examples of this are (a) the popularity of double- and triple-paned windows to lower HVAC costs in homes, and (b) the adoption of touch screens in smart-phones.

The basic analogy is quite obvious here. Most importantly, we note that while designers work with intent within the context of a specific design task, there is no obvious intent guiding the overall process of how artifacts are used and accepted in the larger societal/market environment. It is in this larger context that the authors focus their attention. Next, the authors examine more closely the elements of the analogy, starting with the key process of natural (versus anthropogenic) selection.

Description of Natural Selection: Natural selection, as first defined by Charles Darwin [4], is a process by which characteristics that increase the likelihood of an organism's survival and successful reproduction in an environment become more commonplace within a population, over successive generations. As an example, an increase in humankind's cognitive ability has allowed us to thrive as a species and thus natural selection over many generations of humans has seen an increase in our overall cognitive capacity compared to earlier generations. Another obvious example is the giraffe's neck, which allows it access to food in high places and lessens the likelihood of competition.

Description of Anthropogenic Selection: *Anthropogenic selection* is what the authors call the process in which products that have characteristics preferred by human users will tend to increase the likelihood of that product's success in an environment. These characteristics become more common in the population over successive generations of possibly many products. For example, touch screens on mobile phones were rare when they were first introduced. However, their aesthetics, usefulness, and user-friendly nature have made them highly successful. Touch screens are now common on mobile phones because they increase the likelihood that the phone will be bought. One can trace the evolution of touch screen mobile phones back to touch screen PDAs, and before that to touch screens at electronic kiosks, and before that to "light pens." Anthropogenic selection is not "natural" in the typical sense because the criteria under which it operates come from various artificial and intentional sources, such as: legislation and regulation, science and engineering knowledge, and the influence of marketing (natural evolution, on the other hand, occurs without any intent at all). This is not to say, however, that anthropogenic selection is wholly under intentional control: there are many effects that will influence the success of a particular product over which we have no control at all: market viability, customer acceptance, societal issues, environmental factors, etc.

The authors next consider one of the key mechanisms by which new features are introduced into both biological and artificial entities: mutation.

Description of Biological Mutation: A mutation is a permanent change in the genetic structure of an organism. It can be beneficial or harmful, depending on its effect on the organism's survival (per natural selection). Mutations can be *spontaneous* or *induced.* A spontaneous mutation is the result of a variation in an internal genetic process, such as molecular decay. An induced mutation is a response to an external stimulus or phenomenon, such as exposure to nuclear radiation, prolonged change in nutritional intake, or an intended alteration via, for instance, genetic therapies.

Description of Artificial Mutation: An artificial mutation is a permanent change in a product's design. Because most products are not self-reproducing, mutation occurs through the engineering processes that create the products. A mutation can be beneficial or harmful, depending on its effect on the survival of the product (per anthropogenic selection). Mutations can be *spontaneous* or *induced.* A spontaneous mutation occurs as the result of a variation in the manufacturing and development processes of product development, such as miscalibration of quality assurance equipment, defects in manufacturing equipment due to age, defects in raw materials used in manufacturing, new defects introduced when product parts are replaced during maintenance, or even mistakes that occur during product design. An induced mutation occurs in response to an external stimulus or phenomenon, such as design changes to address perceived flaws, upgrades to manufacturing processes or equipment, changes in current technology, or on-site changes implemented during construction. Such mutations manifest as design changes executed by product designers in response to information fed back to them, for future versions of the product. Even after a product is designed and built, it may incur a mutation during its life. An example is a house that is designed and built with incandescent light fixtures, which are then changed to CFL or LED fixtures at some point. This is a mutation in the design and it occurs well after any engineering processes. If one imagines that a product's design is a model of a product - not necessarily executed *before* the product - then changing the light fixtures changes the product *as well as* its design. One of the possible exceptions here is software, which can in some cases change its own behaviour over its useful life. Hence, the artifact's DNA *is* the design.

There is some divergence here in the analogy, arising from the non-self-reproducing nature of most artifacts. However, the authors adopt a broader perspective in which the design and manufacturing processes that create artifacts are analogous to the self-replication of cells and organism-level reproductive cycles of biological entities. In this view, mutations are events that almost invariably alter individuals of a population of artifacts during their creation. It is possible, but currently very rare, that mutations can be induced in an artifact already in use. One example of this is so-called *product hacking* (e.g. http://hackszine.com) whereby consumers alter everyday products to be used in circumstances for which they were not intended. It is possible that a sufficiently innovative and useful product hack noticed by product developers could work its way into future artifacts. An example here might be the personal customization of mobile device apps and/or operating systems. Thus, while there is a *structural* divergence in how aspects of evolution are implemented in natural systems and (as we propose) in artificial systems, the analogy still holds at the *functional* level.

Finally, the authors extend their analogy to DNA itself, which is the biochemical template of all natural organisms. If the authors' analogy holds, then one should be able to extend it to describe a hypothetical information structure that is the functional equivalent of a biological genome.

Description of Natural DNA: DNA is the inherited genetic material within an organism. Each *gene* is a segment of DNA. The genes are the chemical units that initiate the processes of organism development and growth, that determine the organism's characteristics and the characteristics that are inherited in a successive generations, and also regulate most of the activities which take place throughout the organism's lifetime. [16] Genes ultimately influence all aspects of an organism's structure and function. [9] DNA then is a model of an organism.

Description of Artificial DNA: A design is the information that defines, and is inherited between successive generations of, products: each *gene* is a segment of the design. Genes are the informational units that describe a product's shape, function, construction, usage, and determine its characteristics as well as the characteristics of all similar artifacts of the same class (as well as future batches or production runs of the artifact). Genes ultimately influence all aspects of an artifact's structure and function. "Artificial DNA" is the design of an artifact and a model of the product. In conventional engineering terms, DNA could encompass: database records, CAD models, system architectures, etc.

Again, we see that the fundamental analogy appears to hold. One particular point of interest here, however, is that we are not constrained, as nature is, to use only whatever informational building blocks are available. Indeed, the current general standards of design information are exactly what those structures would be, modulo any shortcomings that might be addressed by future developments in the discipline of product modeling.

If one considers only the descriptions of the artifacts above, there is nothing controversial about them. Yet placing them side by side with descriptions of biological systems brings out their similarities, which clearly underscores the nature of our proposed analogy. In the next section, the authors will more closely examine the specific role of genes in our analogy.

3.2 Genes

It is important to understand the difference between the two types of gene characteristics because they cover different aspects of organism behaviour; namely, *genotypes* and *phenotypes*. *Genotype* refers to the internal, structural composition of specific genes; whereas, *phenotype* refers to the external manifestation, which results from both the genotype and the influence of the environment [7][9]. A genotype must be *expressed* to result in a phenotype. Gene expression refers to the biochemical processes that result in an observable physical, structural, or behavioural effect in the individual. A dormant (non-expressed) gene has no impact on the individual, and its genotype can only be established via DNA profiling. Environmental effects can activate dormant genotypes. For example, some humans have a genetic predisposition to develop cancer; this means they have a genotype that will only be triggered by some external effect - such as smoking cigarettes.

We propose that the same can be said of designed artifacts: every artifact is situated in a certain contextual environment. An artifact will have some characteristics (genes) that do not depend on context and others that do. Artifacts can also have dormant characteristics that are triggered by environmental factors. Two examples of this are: (1) smartphones, the functionality of which changes when its user downloads applications; and (2) affordances unimagined by a designer but realized by a user, such as using a letter opener as a screwdriver.

To further illustrate this with another example, a genotype in a typical house could be the insulation class within the walls. The corresponding phenotype would be the house's thermal behaviour, which would be categorized as, say, an R12 rating. Changing the genotype will result in a new phenotype – e.g. raising the thermal rating to R20. If the genotype leading to an R20 thermal rating is selected by anthropogenic selection (e.g., if owners prefer such houses because they spend less money to heat and cool the house compared to other houses), then the genotype is seen as beneficial and will tend to propagate via construction and renovation of other homes. A more complete version of an analogy between a natural and artificial gene is given in the following figure.

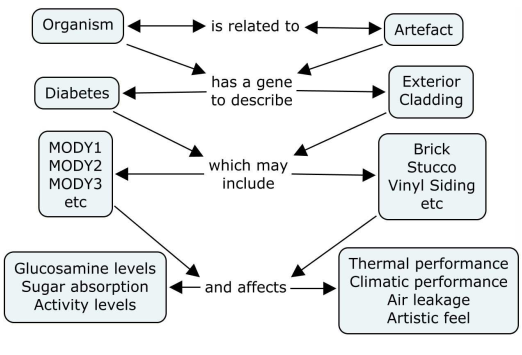

Figure 2. Artifact vs. Organism Gene Comparison

Figure 2 shows the similarities between natural genes and artificial genes, and how those genes induce observable phenomena in organisms and artifacts. We see there is complete symmetry between the natural and artificial conceptualization as rendered by the authors' analogy. In particular, we note that if a complete genome were known for some class of artifact, one can expect appropriate genes could be selected – and thus establish a set of design concepts – by tracing back from preferred characteristic phenomena to the causative genetic structures.

3.3 Lifecycle Processes

In the preceding sections, the authors have shown that it is reasonable to analogize the evolution of products with corresponding processes of natural evolution. To continue the investigation, we must examine the *processes* of these phenomena. That is, if the analogy truly holds, then we should see similarities in the processes involved as well as the structures. The authors have devised such an analogy, between the natural and artificial life-cycle processes; they are depicted graphically in the two figures below.

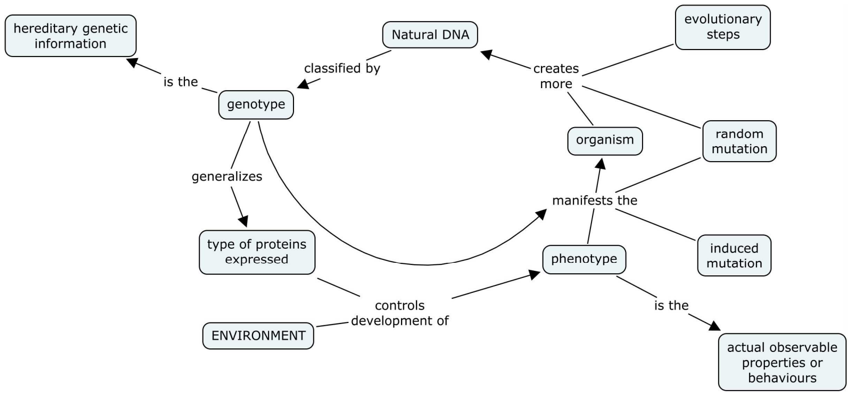

Figure 3. Natural DNA Lifecycle

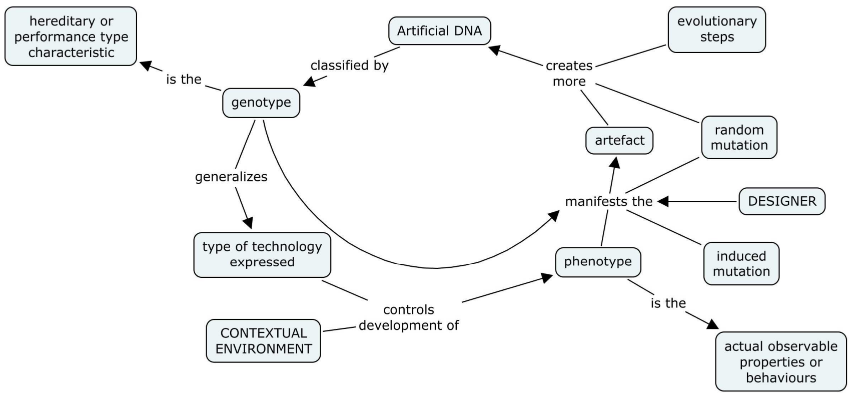

Figure 4. Artificial DNA Lifecycle

We see that the natural and artificial lifecycles are quite similar, which reinforces the sense that the analogy is meaningful. One might argue that an important missing feature of the analogy as rendered in these figures is the appearance of radically new species (a *quantum evolutionary step*) [13]. With respect to the design of artifacts, such quantum steps correspond to highly innovative products. However, in both natural and artificial cases, there is *always* a precursor. In natural systems, even quantum steps are based on changes, albeit massive ones, to existent DNA. In artificial systems, there is always an "as is" context in which some innovation is rooted; in any case, innovation is context sensitive – what is innovative in one situation may be quite conventional in another.
Therefore, a designer's ability to innovate is essentially a kind of mutation. The advantage of innovation over its natural correspondent is that it can be directed by human intention towards solutions that are more likely to be successful. The disadvantage of innovation is that success is based not on the relatively reliable environment of nature (at least with respect to the natural laws) but on the often-irrational landscape of society. Natural evolution drives organisms toward growth to balance the environmental hazards that tend to kill them off. In design, however, many artifacts are designed for reasons disconnected from simple survival; thus the force of growth is often unbalanced in artificial evolution [12].

We can, however, recover the sense of balance by considering the long-term effects of sustainability. For instance, there is no *direct* environmental force acting against individuals who consume significant amounts of gasoline to power automobiles. Growth here is uncontrolled by the human/societal environment. However, if we consider the long-term effects of fossil fuel consumption, we do find an environmental force that acts against those individuals (as well as others). This is an example of how the analogy can help to embed factors of sustainability directly in the design process itself.

The authors believe that building and refining on this analogy between natural evolution and artificial design can increase the efficiency of the design process, but also help improve the sustainability and overall fitness of the designed products within their contextual environments.

4. Discussion

In the preceding sections, the authors detailed a proposed analogy between natural evolution and how artifacts and designs change over time. One may use the analogy to develop new ways of designing, and determine if the expected benefits are realized. This is currently on-going research. In this section, the authors describe some of the implications of the analogy for design methods and processes, and outline how we will continue our study.

Figure 5 below shows how the structure of an artifact is similar to that of an organism, and how the specific elements of each may correlate. In the figure, bracketed words in the description for artifacts show the analogous terms that are used for organisms. As can be seen, the two outlines fit well together and show that an analogy between the two violates neither our current knowledge of evolution, nor conventional thinking in design.

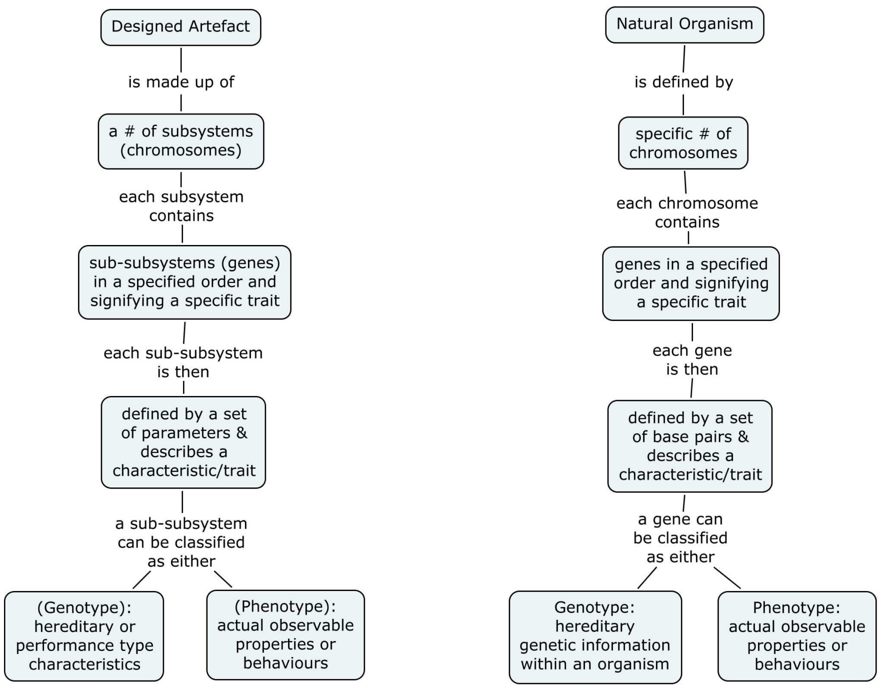

Figure 5. Artifact vs. Organism Genetic Makeup

These *artificial genomes* do not currently exist; developing them is part of the authors' research. While we are not constrained to use simple structures (chemical or otherwise) to construct our genomes, a thorough understanding of the biological composition of DNA and genomes is needed. This will be the next step of our work.

Next, there must be a way in which to describe and define each gene within the artificial genome. These gene definitions must be understandable by all users and should interact (informationally) as do natural genes. *Design* *patterns* (per Alexander [2]) will be used to create each gene. The patterns can interrelate, just as natural genes do, and will combine to create a full *pattern language*; i.e. an artificial genome. Different types of artifacts (analogous to biological "species") will be described by different pattern languages. Each pattern language would then be the complete collection of genes required to fully describe a single artifact type – a house, for instance. Thus, another stage of the research will be to create these patterns and pattern languages by analyzing pre-existing examples for each artifact type that we wish to create the genome for. Many existent houses would have to be analyzed in order to create the genome for a house, for example.

A pattern language describes more than just the collection of patterns; it can show how the interrelations between patterns can give rise to emergent behaviours. Emergence theory [8] describes this phenomenon and it will be useful for describing the artificial genes and their interrelations.

To execute the creation and analysis of the artificial genome, a process similar to gene mapping will be carried out. This process would encompass the analysis of existing artifacts of a specified type and the creation of the genetic representation (or "genome") of that artifact type, using a pattern language. Also, since one goal of this research is to embed sustainability directly into design, then sustainability aspects will have to be taken into account when creating the genome. This phase would constitute a "DNA Sequencing Phase" and would need to be done on existing products before the method is used to design a new product.

Once the genome for an artifact has been created, the authors envision using this representation to design new artifacts through the process outlined in this paper. Here, a design for a new product would be executed by using the DNA analogy with that artifact type's genome. Recalling that the genome is then the collection of possible genes for a product and that those genes each have within them the information necessary for the design, the design could then be carried out by using that genome to specify the genes needed to solve the problem, as defined in the problem space. This phase we could term the "Artifact Creation Phase" and would study the use of the genome in helping design practices to achieve faster, better, cheaper, and more sustainable design.

This entire phase of artifact creation follows a similar process to current design methods, but with the added benefit of having available a pre-selection of known characteristics by way of the genes in the genetic analogy, which are known to satisfy the conditions in the target environment. As can be seen by the figure below, there are three major stages that encompass designing via the genetic analogy.

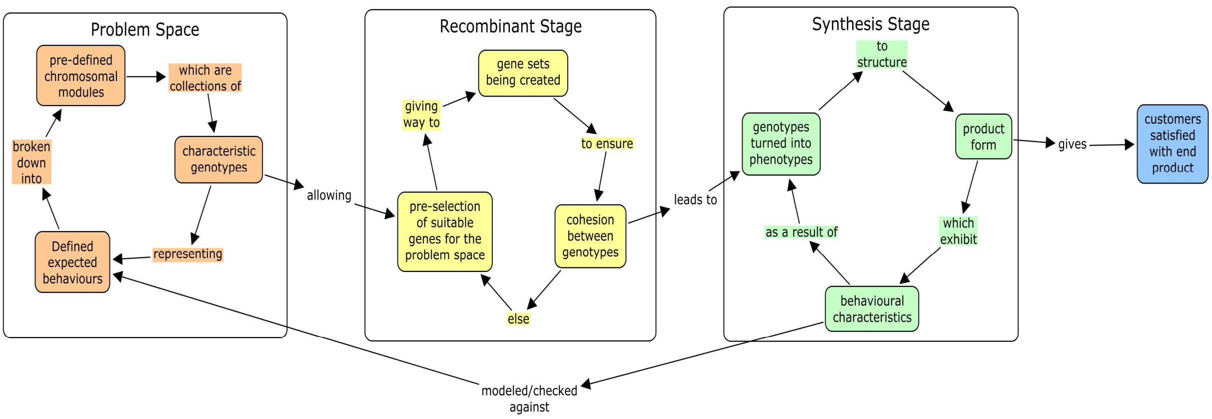

Figure 6. Process of the Artifact Creation Phase

Finally, in order to evaluate the performance of the genome in creating an acceptable solution for the problem, there would have to be a measure of fitness, or "goodness of fit" [1] between the problem and solution spaces. The fitness can be seen as the methods that evaluate how well a proposed artifact (a design) addresses a given problem. Choosing the design of best fit was shown earlier to be analogous to natural selection in that successful (fit) products are most likely to prosper in the contextual environment for which they were designed. In this way, we are trying to ensure the success of a chosen design and the propagation of that design through time.

Another interesting emergent aspect of the analogy is that of induced mutation in the design. Since the genome will consist of all available options for the specific genes of the artifact, then it stands to reason that the designer can induce specific mutations into the design to see what the result will be. This can be done in the pre-design phases and analyzed to see if the net benefit of the mutation is positive on the overall fitness. Here, the designers have an advantage over nature in that it is possible to see the results of a mutation before finalizing the design, whereas nature only realizes the results of a mutation after a an organism type has developed and has existed in the environment. Therefore, it is possible to experiment with these mutations to see if they result in a better product, without having to manufacture the product, only to see it fail.

5. Conclusions

Artifacts have specific elements that are designed to fulfill certain functional properties. This can be likened to a gene which defines a certain characteristic or function in a living organism. Further, organisms have many genes that interact on more complex levels to describe their more complex functioning; similar to subsystems in engineering design. It could then be possible to "build" the artifact we want from a collection of identified genes, comparable to the way we might build a living organism for a certain environment.

Currently the work rests in this state; that the framework has been identified and laid out ready for the elements of the genome. Future work for the authors will include the creation of a genome for a product type (perhaps a house). Testing of the usefulness of the genome for designing the product will be carried out by giving designers a design problem and asking them to use the design by DNA analogy in order to solve it.

If the proposed artificial genes include sustainability principles and if the anthropogenic selection prefers sustainable solutions, then artifacts constructed with those genes will tend to be sustainable. In this way, sustainability can be built into design theory to ensure that it is ingrained in the very roots of the artifact being designed, instead of being an afterthought (as is currently done in most cases). This is of course dependent on the fact that we are currently looking only at the technological aspects of the design and not the cultural aspects, since we cannot control the poor cultural influences on products, which may otherwise prefer a non-sustainable solution. Also, since nature is inherently sustainable in its approach to design, then it follows that if we use a design method that is analogous to the way nature designs, then our products should also be sustainable.

Further, it is known that analogies reduce problem complexity, since they reference something that is familiar to the designers. In this way, the genetic analogy should help reduce complexity of current design problems, since the analogy can be drawn at many levels and throughout the entire design process. Also, pattern languages are used to break down complex problems into easier to handle segments. By using patterns to structure the analogy, we can conclude that complexity in design problems should be greatly reduced. It is thought that if each gene is represented by an exclusive pattern, then it is possible to build the artifact in accordance with the dependencies inherent within the pattern language itself.

It has been shown that both engineering design and pseudo-design in nature share many aspects, such as: a similar design process; life-cycle processes; phenomena like evolution, mutation, and natural selection; a goal of sustainability; and design complexity. Therefore, it is possible to argue by way of analogy that there could be an even greater number of commonalities between natural and artificial design, which have not been discussed here.

Finally, it is hoped that by providing a natural analogy for design that it will promote a means by which to increase the rate at which we evolve current designs and that our methods of natural selection will help to ensure that the best possible designs are the ones which flourish. This is feasible since there is no specific lifetime for any one generation of a product and that if a new product is designed which is a better fit for its environment, then it will naturally be chosen by humanity. So, it is possible to see that we have within us a means to evolve our own designs, which is faster than that of nature, and that hopefully our designs will soon reach a level of sustainability which is beneficial for our own contextual environment; the Earth.

6. Acknowledgements

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7. References

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