COMPLEX NETWORKS AND COMPLEX SYSTEMS FOR SUSTAINABILITY

A Nature-based Framework for Sustainable Product Design and Development

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Abstract: Nature-based systems are efficiently designed and are able to respond to many system requirements such as scalability, adaptability, self-organization, resilience, robustness, durability, reliability, self-monitoring, self-repair, and many others. Using nature's examples as guidepost, there is a unique platform for developing more environmentally sustainable products and systems. This position paper makes a case for an interdisciplinary approach to sustainable design and development. This paper suggests that the design should not only mimic natural behaviours but should benefit from natural phenomenon (e.g, wind turbines). The paper proposes a conceptual modeling system framework, whereby physical products and systems are designed and modeled with the added benefit of how similar systems work in nature. Developing such a system in nontrivial and requires an interdisciplinary approach. To realize this system will require a merging of analytical and computational models of nature systems and human-made systems into a single information system. In this position paper, we discuss the framework at a birds-eye view.

1 INTRODUCTION

There has been a recent growth of research in network design and analysis with the desire to apply newly developed ideas and frameworks to many different disciplines. Sources of these ideas and frameworks have been the results of observing natural complex systems such as ecological and biological systems. These systems are efficiently designed and are able to respond too many network requirements such as scalability, adaptability, self-organization, resilience, robustness, durability, reliability, self-monitoring, self-repair, and many others. Using nature's examples as guidepost, there is a unique opportunity and fit between environmental *sustainability* and using *natural systems* as a platform for future innovation in sustainable design. To fully benefit from using natural models, the concepts as well as research endeavours must be extended to incorporate the complete natural ecosystem. When we typically think of using nature as a model, it implies mimicking a feature of an organism when designing a product. However to create transformational results, it is important to consider what aspect of the product design supports the environment and what aspects of the environmental design supports the product. This can enable designs that not only utilize nature's resources but also give back to the environment. Many of these issues are being addressed within the industrial ecology field (Frosch and Gallopoulos, 1989). It is important that all stakeholders (society, researchers, government) understand the benefits and the unique knowledge that can be gained by applying nature-based concepts to complex-engineered system design. Standing in the way of more efficient designs is the *knowledge gap* between stakeholders that are attempting to address the issues. Figure 1 shows a simple conceptual description of the system. The system consists of analytical or computation models of natural and synthetic phenomenon. The models are merged into a Computer-Aided Design (CAD) system that incorporate details from both models during a product or system detail design phase.

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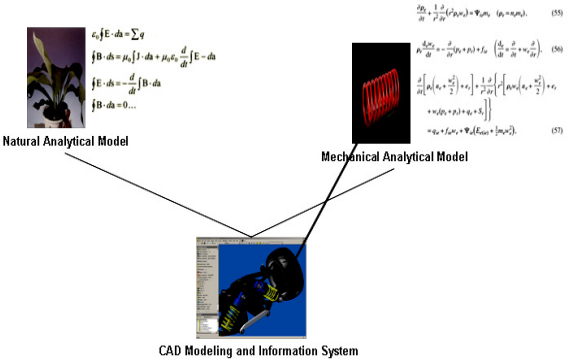

Figure 1: Conceptual Description of New Modeling Information System for Shock-absorber design.

2 IMPORTANCE OF PROBLEM

Sustainability is an important topic with lots of discussion and debate. Some of the key areas of concern are global warming, renewable energy, recycling, biodiversity, pollution, and alternative fuels. The United Nations released a report that attempts to quantify environmental damage done by the world's 3000 largest companies (Jowitt, 2010). The value of damage was estimated at ~$2.2 trillion. Their findings and results farther highlight the importance of sustainable design.

Why should we attack this problem from a design perspective? Historically there has been a close correlation between economic growth and environmental degradation: as communities grow the environment declines. This trend is due to the increase in production and use of new technologies, products and services. There is concern that, unless resource use is properly managed, modern global civilization will follow the path of ancient civilizations that collapsed through overexploitation of their resources. While conventional economics is concerned largely with economic growth and the efficient allocation of resources, ecological economics has the explicit goal of sustainable scale (rather than continual growth), fair distribution and efficient allocation, in that order (Herman and Farley, 2003; Costanza and Farley, 2007). Sustainability studies analyze ways to reduce (decouple) the amount of resource (e.g. water, energy, or materials) needed for the production, consumption and disposal of a unit of good or service whether this be achieved from improved economic management, product design, new technology, etc (Daly, 1996). It is necessary that future product design and development puts into practice the principles outlined in industrial ecology and seek to develop and design products and services that work symbiotically with nature. It is necessary that additional funding and research be directed toward solving these problems which will require the collaboration of varies domains and expertise.

3 KEY CHALLENGES

Environmental sustainability issues are typically deeply embedded in the societal structure. Furthermore, there is no one accepted description of sustainability for which an organization can assess itself (Chen, 2001). Oftentimes, a sustainability effort of a product development organization might be the optimization of a production line. Although this is a great benefit, we should take full advantage of the opportunity to innovate along all dimensions (production, design, supply chain, etc). However, there is lots of opportunity to create new innovations as an organization develops more sustainable products and technology. Unfortunately, some organizations have made the erroneous assumption that they could command a price premium for "environment-friendly" products. When such products or projects failed to meet financial growth requirements they may have been subsequently cut. Also, some "eco-" products have trade-offs that were or are not acceptable. For example, although the electric car produces a lower level of pollutant, it does so at the expense of duration and speed (de Neufville et al., 1996). Consequently, the needs and the desire of many consumers are not successfully met. Environmental sustainability is a critical need that requires action that must lead to transformational results and improvements in product development. This need is continually echoed via many global policies and goals. There are environmental requirements that many organizations must adhere to in the future. Meeting these requirements will require new and innovative solutions to product development and design.

The need for nature-based sustainable product design and development is not only a *national* but *global* in scope. As new environmental policies are adopted around the world the competitiveness of products and technologies are at risks. It is necessary that new products interact in a more symbiotic relationship with nature. The need is *critical* because of the continuing increase in the nation's population resulting in the increase usage and disposal of products and technologies. As the number of people

using technologies increase, the amount of waste and by-products of the usage increase as well. It is important to minimize the negative impacts of technological advancements on the environment.

4 RESEARCH AND CONCEPTS

Creating environmentally sustainable designs is a multi-disciplinary endeavour, requiring the understanding of complex systems that are interacting. There are currently no test-bed or platform that provides real-time comparison between natural systems and human-made engineered systems during the design/development phases. Access to this information is only available if a team member is knowledgeable in applying nature-based ideas to product design and development. In order to have transformational results in sustainable designs, it is important to not only understand the artefact, but how the artefact functions in its environment as well.

One concept that has been gaining attention in regards to nature-based designs is **Biomimicry**. Biomimicry is the science and art of emulating nature's best biological ideas to solve human problems (Benyus, 1997). In general this concept has been used when suggesting to mimic specific features of a natural organism, but if we consider both the biological entity (e.g., fish, gecko, etc) as well as the environment (e.g., lake, pond, rain forest, etc.) conjointly there is the opportunity to develop and design new systems that are both innovative and sustainable. Supporting more research efforts in this area is critical to developing new knowledge in order to solve many key environmental issues (pollution, biodiversity/conservation, recycling, global-warming, etc.) facing the world.

Much of the work in biological and nature-inspired systems have been focused on designing a product with the features of the biological model; for example, understanding the design of the lateral line a fish and then using this information to design better sensors that mimics the functionality (Yang et al., 2010; Chen et al., 2007;). This could/should be extended to encompass the understanding of the habitat and the sustained environment where the fish resides and grows in population. It is necessary to understand what aspect of the fish design supports the environment and what aspects of the environmental design supports the fish population. This can enable designs that not only utilize nature's resources but also give back to the environment. The idea of using nature as a model is not new, but to advance this idea will require system-level thinking and not focusing only on mimicking the features of a natural system (product-design-focused industrial ecology).

Oftentimes product development engineers and designers have significant knowledge gaps regarding the complex behaviour of some ecological and biological systems. Tasked with designing environmentally sustainable systems results in trying to optimize current designs or use new tools from the same engineering bag. Unfortunately, the knowledge gap does not typically lead the engineer or the designer down the road to studying biological systems which could lead to innovated solution. However, the inter-disciplinary nature of complex systems – biological and man-engineered - creates the opportunity for collaboration.

5 POTENTIAL IMPACT

The desired output of the research is a comprehensive, implementable, and usable set of analytical and computational models and analysis tools covering both micro and macro dimensions. Such a system would allow product designers/developers to compare natural ecosystem ecology to complex-engineered product ecology systems during the design and development phases. This toolkit will consist of a number of nature-based and engineered primitive models. These primitive models will be the building blocks for future product development and design. Additionally, it is expected that the analysis tools would also provide an assessment of emergent behaviour (i.e., impact on environment, etc.) given the design of the product and system.

There are current efforts to develop a database documenting various features of natural entities and how they may be adopted for design components in engineered-systems. This approach provides great benefits and opportunities from a purely design perspective, but to move toward sustainability; the products must be design with an understanding of the natural systems in which it will exist as well as interact. In addition to analytical and computational tools, overflow from this research will lead to new theories and understanding of the coexistence between human-made technologies and natural systems (industrial ecology). The desire is that the knowledge gaps between the stakeholders will be minimized during the collaborative research efforts. The results of this research will be instrumental in

helping decision-makers with long range conservation, environmental, and industrial policies.

To create the transformational results needed, this research endeavour will span across a diverse range of disciplines. The expertise of entomologist, ecologist, sociologists, biologists, engineers, and designers will be crucial in realizing a set of robust tools. Typically funding is dedicated to anyone of these disciplines alone. However, it is important for funding to address the highly inter-disciplinary nature of this endeavour. Ideally, this research endeavour will support the collaboration of many institutions, both private and public in industry and academia.

6 CONCLUSIONS

The research theme discussed in this position paper is focused on developing and designing environmentally sustainable products and systems. Sustainability is a critical global initiative. Future products and systems must be designed in such a way that works-with and supports the environment. To effectively address sustainability issues requires the collaboration of many different disciplines. In this whitepaper, we discuss biomimicry as a driving concept within this design philosophy. It is crucial that funding directed toward this theme is inter-disciplinary so that the greatest benefits can be gained. The vision for this research is:

- To develop new analytical and computational tools and techniques that will enable product development engineer and designers to create environmental sustainable products that work in harmony with nature.
- To aid decision-makers in policy making.
- To promote collaboration amongst many distinct disciplines. This can lead to revolutionary, transformational results and capabilities.
- To minimize the knowledge gaps between stakeholders involved in developing solution to problems in environmentally sustainable product design and development.

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