Affordance-based Reverse Engineering of Natural Systems with Possible Corruption

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Abstract

The techniques of reverse engineering have been successfully applied for many years, often in spite of a corrupted or damaged specimen. But recently the application of reverse engineering in unforeseen areas has led to new discoveries and a better understanding of what an engineered system offers its potential end users. With affordance-based reverse engineering principles, we aim to analyze the effects of corruption on a specimen. How does corruption alter the perceived affordances of the object? Can lessons learned by reverse engineering man-made artifacts be successfully applied to natural systems? An affordance-based model helps to ascertain the positive and negative effects associated with each part of a system. Discovering the purpose of the individual parts of the system allows for a greater understanding of the purpose for which the entire system was engineered.

An affordance-based analysis of manmade artifacts that have experienced corruption may have helpful applications in thinking about natural systems. Hypothesizing that a system may have undergone corruption allows for the possibility that the system may possess a modified set of positive affordances that it would not have otherwise enjoyed. Viewed in this light, corruption and the resulting affordances may be seen as an occasion of the inventive problem-solving technique known as "blessing in disguise" or "making the devil work for you." Using this method offers new and exciting options for some of the mysteries with which scientists and theologians are currently wrestling. A Christian theodicy based on this approach may be particularly interesting to unbelieving scientists and engineers.

Introduction

Being an engineer by training, and having several years of engineering experience in industry and academia, I find it relatively easy to relate to God in his role as creative problem solver and engineer of the universe. So it seems natural to me to investigate his works of creation from a reverse engineering perspective. Reverse engineering is simply the dissection and analysis of any engineered system in an effort to uncover the secrets behind its original design. Affordance-based reverse engineering chooses to focus on the relational aspects of design, such as what is provided to the end user, or what one part of a system provides to another part of the system. The reverse engineering process will typically become more difficult if a system has been corrupted or damaged along the way.

In the first chapter of Romans, Paul writes about how God's eternal power and divine nature are clearly seen, "being understood through what has been made." It seems clear that he is referring to a basic form of reverse engineering of which every person is capable. He goes on to write about the corruption that can occur in human beings if they reject this knowledge and pursue their own plans. Thus from a Christian perspective, any attempt to reverse engineer natural systems is doubly complicated by possible corruption within nature (even biological structures), and corruption in the human investigator. However, framing this investigation in

terms of reverse engineering brings mature techniques from the field of engineering to bear, and results may be useful in sharing the gospel, especially with skeptical scientists and engineers.

The purpose of this paper is to explore the idea of applying affordance-based reverse engineering to natural systems that may have experienced some type of corruption. In this case, corruption consists not only of moral depravity and perversion of integrity, but also deviation from appropriate function or purpose of the original engineer. Of course, this assumes that original purpose is known with a high degree of confidence. The problem of theodicy (the defense of God's goodness, omnipotence, and omniscience in light of significant evil and suffering in the world) also arises in this context. Why did God allow the universe to become "corrupted?" The idea that experience from the fields of affordance-based design engineering and forensic engineering (the study of why engineered systems go wrong) may shed light on this problem is also explored. Interactions such as these between the fields of science, engineering, and theology (among others) are thought to be a valuable part of the undergraduate science and engineering curriculums at a Christian university. Skeptics are positively influenced when they observe that Christians have thought about these issues. Furthermore, graduates are better prepared to rationally articulate a Christian worldview and give compelling reasons for their hope.

Affordance-based Reverse Engineering

The process of reverse engineering has been used for many years but recently the application of reverse engineering in new areas has led to discoveries and better understanding of the functions and affordances of both natural and artificial systems. Knowledge of the bacterial flagellum, for example, is due largely to the application of reverse engineering techniques to biological systems.[1] Analyzing the structure as that of a motor sheds light on the affordances of the individual parts of the bacterial flagellum. As another example, at Stanford University a biologist and an engineer teamed up to study the heat shock mechanism of E. coli-bacteria,[2] using reverse engineering techniques such as "subtract and operate."[3] They found that system performance degraded only slightly when feedback or feedforward pathways were removed to simulate damage or corruption. They claimed that this robust system is remarkably similar to what a well-trained control systems engineer would devise. In this paper, reverse engineering principles are applied to explore the effects of corruption on a system. How will this corruption alter the perceived affordances of the system? Can there be some good that comes out of something that was originally viewed as negative?

Consider how disease in the human body can be seen as a form of corruption, but once one has adapted, and the proper antibodies are developed, the disease no longer poses a threat. History provides a distinctive example of this happening with George Washington. As a child Washington came down with a case of smallpox. While, at the time, this corrupted his system, later on in life at Valley Forge he was better able to lead as he was not susceptible to the disease. Washington also used the new but controversial idea of inoculation to reduce the severity and spread of the disease. Thanks to this action, the Continental Army stationed at Valley Forge was able to survive the epidemic, persevere through the harsh winter, and continue on in the battle for American independence.[4]

To begin addressing the above questions, a systematic affordance-based approach[5] is used to determine if the effects on the system cause the affordances of the system to change. An affordance-based approach helps to ascertain the positive and negative effects produced by each

part of the system and their interactions. One such way to utilize the affordance-based method of analysis is with an affordance structure matrix. This tool, developed by Jonathan R.A. Maier and Goerges M. Fadel,[6] shows a representation of the interconnections between the parts of a system and the affordances that the system offers the end user, or the affordances that one part of the system offers to another part. A matrix lists the parts of the system across the horizontal axis with the affordances along the vertical axis. The body of the matrix is used to indicate whether an affordance is positive or negative, and can also provide an estimate of the quality of each affordance. There is also a side grid and top grid that shows how the affordances and parts of the system are connected with each other respectively. The ability to show both when a part of the system helps and when it hinders another part is especially useful to this project. Thus identifying the affordances of the individual parts of the system allows for a greater understanding of the purpose for which it was engineered. This approach to unraveling the mysteries of natural systems has been introduced in a previous paper,[7] which briefly analyzed the system of life on earth. A rudimentary affordance structure matrix for such a system is shown in Figure 1.

		Land	Water	Light	Air	Plants	Animals	Total
+AUA	Life	x	x	x	x	x	x	6
	Education	x	x	x	x	x	x	6
-AUA	Death	x	x	x	x	x	x	6
	Pain			x		x	x	3
+AAA	Food	x	x	x	x	x	x	6
	Shelter	x	x			x	x	4
-AAA	Sickness	x	x	x	x	x	x	6
	Disasters	x	x	x	x	x	x	6
	Total	7	7	7	6	8	8	43

Figure 1. Simple Affordance Structure Matrix for the System of Life on Earth

The extent to which the affordance structure matrix is populated also indicates a measure of "designedness" of a system. A skillfully engineered system makes use of as many interactions between parts as possible to produce positive affordances, while minimizing negative affordances. A part that serves multiple purposes simultaneously represents ingenuity and an efficient use of resources. This is evident when considering the characteristics of life on Earth and the structures and mechanisms of systems biology. On the contrary, consider how sparsely populated the affordance structure matrix would be for a random collection of parts, or a poorly or inefficiently engineered system. Thus it is widely acknowledged that many natural systems

appear to be fine-tuned or engineered for a purpose, namely the evolution and sustenance of life, but the conundrum arises when we consider the negative affordances associated with the human condition, and the evolutionary process in general. These seem to be inconsistent with the extreme engineering genius that appears to lie behind the natural realm. Theologian Christopher Southgate formulates a "theodicy in light of evolution" which downplays the idea of corruption in favor of "disvalues" being an inherent part of the system, and the "only way" God could bring forth the valuable creatures he desired.[8] Perhaps what humans perceive to be negative affordances, in our limited perspective and understanding, may turn out to be positive affordances once we are able to perceive the "big picture." It is hoped that the quantitative aspects of a reverse engineering approach will provide additional insight that will lead to a proper balance between the concepts of corruption and inherent disvalue. The challenge comes in attempting to make useful measurements in extremely complex and inherently non-quantifiable systems.

Help from Business and Theology

Modifying our definition of "measurement" has also helped in this analysis. In his book *How to Measure Anything: Finding the Value of "Intangibles" in Business*, Douglas W. Hubbard describes a different approach to measurement that may help with understanding these concepts. His definition of measurement is "a quantitatively expressed reduction of uncertainty based on one or more observations,"[9] as opposed to the normal definition as a quantitative description of an object, such as size. Reconsidering the concept of measurements can shift the focus from finding the exact purpose of a system to that of becoming more confident of its purpose. While it is still important to find the original purpose, and it is no doubt the end goal, understanding even a small amount allows for better comprehension of the whole. We understand that original purpose cannot always be determined with confidence through reverse engineering, and we are aware of the potential for misinterpretation. Therefore, we attempt to cautiously approach the determination of purpose in nature with humility and objectivity.

Hubbard also describes a process called "decompose it". This describes how "many measurements start by decomposing an uncertain variable into constituent parts to identify directly observable things that are easier to measure." The thought process behind this is similar to that used in the affordance structure matrix. The complex and uncertain parts of the system are dissected and the affordances are analyzed. Applying these ideas from the business world is a prime example of how research from one discipline may unexpectedly contribute to success in another.

Theology is another field which may lend insight into the attempt to reverse engineer natural systems. Alister McGrath contends that a Christian Worldview offers a particularly illuminating framework for making sense of the natural world. In his book *Surprised by Meaning*,[10] he explores two (among many) aspects of Christian doctrine that assist in this endeavor: i) the idea that humanity bears the image of God and ii) the notion of an "economy of salvation." One of the implications of the first theme that has been historically recognized by the church is that humanity was created with the capacity to make sense of God's creation. This helps to explain the intelligibility of the universe. Engineers know that for reverse engineering to be possible, there must be an appropriate match between the intelligence of the investigator and the complexity of the system under investigation. This is exactly what we see with human beings studying the natural world.

The second theme sets out the idea that God's interaction with the world is described in terms of a narrative of creation, fall/corruption, redemption, and final consummation. McGrath reminds us that "there is a profoundly eschatological dimension to an authentically Christian natural theology, in that the natural order should be observed in the light of its goal [or purpose], not merely in the light of its origination…The Christian framework of the economy of salvation helps us to appreciate that we have to locate this problem [evil, corruption, and suffering] on a theological map. The world was created good; one day it will be restored to an even greater goodness." Perhaps God's allowance of evil, and hence human failure, into his creation results in certain positive affordances that enable the realization of this greater goodness. Engineering educators Matthew Green and Paul Leiffer point out that learning through experiencing failure, what they call "flearning," seems to be a crucial step in eventually arriving at the truth.[11] Engineer and author Henry Petroski appears to agree, as he describes in his book, *Success through Failure: The Paradox of Design*."[12] In any case, it is not surprising that human investigators, as travelers in the midst of this journey, experience a self-referential entanglement with nature that results in insufficient information to answer these questions with certainty.

However, affordance-based analysis of manmade systems, along with an open mind as to the reduction of uncertainty, appears to have valid applications into natural systems. By making the assumption that a system could be corrupted, allowance is made for the possibility of changing affordances. Using this method offers new and exciting resolutions for some of the mysteries with which scientists and theologians are currently struggling. It allows for the possibility that new positive affordances may result from what originally appears to be corruption of, or damage to, the system.

An example of this comes from the history of radial keratotomy, where eyesight is enhanced by making a series of incisions on the surface of the eye. This surgical procedure originated partly because of a bicycle accident in which a child fell and shattered his eye glasses. Unfortunately, pieces of glass became embedded in his eye. But actually, much good came from this accident because upon removal of the pieces of glass, it was discovered that the child's eyesight had improved! As a result, a surgical procedure was developed which eventually contributed to the improved eyesight of millions of people.[13] This example is included simply to demonstrate that positive affordances can result from seemingly negative occurrences.

One can also turn to Scripture and see the support for good coming from seemingly desperate circumstances. Romans 8:28 states, "We know that in all things God works for the good of those who love him, who have been called according to his purpose." Note that it says "in *all* things God works for the good of those who love him." Extrapolating this to our approach implies that even what appear to be negative affordances can eventually turn out for our good.

Mankind: A Shoddy Piece of Work?

Physicist and science writer Phillip Ball recently published an article in *Nature* entitled, "What a shoddy piece of work is man."[14] In this article he expounds on the idea that "the human body is certainly no masterpiece of intelligent planning." First of all, for someone to be "certain" of such a conclusion, one would have to know much more about the origin and destiny of living systems than mankind currently possesses, or is ever likely to possess. This kind of "overstating the case" occurs on both sides of the science and theology debate. It is unproductive, often leading to over-emotional responses, and should be avoided, and quickly corrected when recognized. Even so, it is understandable how Ball might come to his conclusion when one

considers all the negatives factors associated with not only the human body, but also the human condition.

Ball refers to the recent work of evolutionary biologist John Avise, who published a book last year entitled *Inside the Human Genome: A Case for Non-Intelligent Design*,[15] and a *PNAS* article entitled, "Footprints of nonsentient design inside the human genome."[16] Avise makes his case by pointing out the deadly effects of malfunctioning aspects of the genome, seemingly wasteful elements, and baroque arrangements that no conscious engineer would conceivably produce, or even allow. Once again, it should be pointed out that in order to properly judge the merits of such a hypothesized design, one needs more complete information concerning the engineering objectives, and other metaphysical factors that might bear on such a design.

Perhaps Ball and Avise might consider other possibilities such as the idea that natural systems have undergone some kind of corruption throughout their history, or even that the design engineer allows negative factors to be introduced for the eventual good of his creatures. Instead, Avise closes his article by asserting that "Evolution by natural causes emancipates religion from the shackles of theodicy," since God is no longer responsible for the "gross evil and suffering in the world." Avise is corrected on this point in a reply to his article by Michael Murray (philosopher) and Jacob Schloss (biologist).[17] They point out that "positing that God delegated the task of generating life to insentient evolution merely ushers in an explanatory regress that serves to illuminate rather than ease the problem of the evils resulting from the operation of nature."

To Avise's credit, he appears to receive this correction, as made evident in his response to Murray and Schloss,[18] and is humble enough to invite non-scientists into the dialogue. In reference to "molecular faults that cause vast human suffering," he writes, "It is now time for theologians to step up to the plate and perhaps help us to understand the philosophical implications of this rather disturbing reality." This openness to cross-disciplinary dialogue with non-scientists is a welcome development that should be applauded by both sides of the debate. Engineers should also join the scientists and theologians at the plate since much of the discussion involves the reverse engineering of complex biological systems. In addition, this is the kind of dialogue that should especially be going on at Christian universities around the world. Students in science, engineering and theology all benefit from interdisciplinary dialogue when wrestling with the worldview implications of new discoveries. This paper derives from just such an interdisciplinary research group of undergraduate honors students under the direction of the Dean of the College of Science and Engineering at Oral Roberts University.[19]

Reverse Engineering of a Corrupted Specimen

As an example of what can be learned through reverse engineering, consider the Antikythera Mechanism. Around the beginning of the 20th century, a major archeological find was made in the discovery of the contents of an undersea shipwreck off the coast of the Greek Island of Antikythera. Many valuable artifacts were recovered from the wreck, which was dated to about 100 BCE. In addition to beautiful marble statues and ancient artifacts, a curious, corroded and coral-encrusted block of an unknown nature was retrieved and placed in the basement of the Athens Museum. After some time, it dried out and cracked apart to reveal the edges of metal gear wheels. This caught the attention of researchers since complex gear trains were not thought to exist at any time near 100 BCE. This realization was the beginning of over 100 years of the most fascinating reverse engineering work in the history of technology. Jo

Marchant tells the intriguing tale of the Antikythera Mechanism in her 2010 book, *Decoding the Heavens*.[20]

The specimen was incomplete, in several pieces, and was so badly corrupted that initial attempts at reverse engineering were very discouraging. However with painstaking effort over a period of about 100 years, the corruption produced by two millennia of sea water was teased apart from the original engineering that went into the device. With the help of advanced measurement systems like x-rays and sonograms, functioning replicas were eventually produced by multiple investigators. They were able to identify the parts of the mechanism (including 28 different gears) and how those parts interacted (providing part-to-part affordances) in delivering affordances to an end user. Marchant provides the following insight, "Scrutinizing the details of the gearwheels and inscriptions, however, wasn't the only way to investigate the mechanism… archaeologists also studied the rest of the salvaged cargo [and culture of the time]. Their discoveries help to paint a vivid picture of when the ship sailed, where her load was being taken, and the sort of world from which she came. From there, we can guess at the origins of the Antikythera Mechanism itself, and how it ended up on its final journey." Ultimately, it was recognized that the mechanism affords a mechanical simulation of the motion of the moon and planets including the prediction of eclipses. In effect, it is believed to be one of the first analog computers, about a thousand years earlier than was ever thought possible.

There are a few things to be gleaned from this classic example of reverse engineering of a man-made system, and perhaps applied to natural systems. The quality of engineering and workmanship reflects on the original engineer. Marchant records how carefully engraved letters in the outer casing of the mechanism indicate the work of a "master craftsman," rather than an "unskilled laborer." Information about origin and destiny may also be uncovered by expanding the investigation beyond dissection and measurement of the specimen. Relationships between potential users of such a mechanism and those ingenious enough to engineer it were investigated. The history and culture of the time, in addition to the other artifacts with which it was found, helped to unravel the mystery of its origin and purpose. This is the nature of reverse engineering projects: all possible information that could be pertinent in recovering original design information is considered.

It therefore seems clear that in reverse engineering natural systems, the standard approach of methodological naturalism may be inadequate. Certain phases of the scientific method like experimentation, measurement and testing necessarily require this constraint, but other phases such as theory-forming and model-building needn't be so restrictive.[21] In addition, affordance-based reverse engineering emphasizes the relationships that exist within the "big picture" of design and reverse engineering. These are the relationships between the designer, the artifact, the end user, and the investigator or reverse engineer. Figure 2 illustrates these relationships for the case in which the artifact is the entire cosmos. In the context of a Christian worldview with a traditional understanding of mankind's fall, these relationships provide a rich backdrop for explaining the origin and nature of corruption associated with the human condition.

Something significant happens when a human being, typically thought of as the end user, allows him or herself to humbly take on the role of a sincere investigator. To embrace the role of investigator, one must admit their own ignorance; acknowledging their need for answers. The universe has been engineered to reveal truth, albeit often through the "school of hard knocks," and we were engineered to be truth seekers. This is consistent with Jesus' teaching (Matthew 7:7-8) to, "Ask and it will be given to you; seek and you will find; knock and the door will be

opened to you. For everyone who asks receives; the one who seeks finds; and to the one who knocks, the door will be opened."

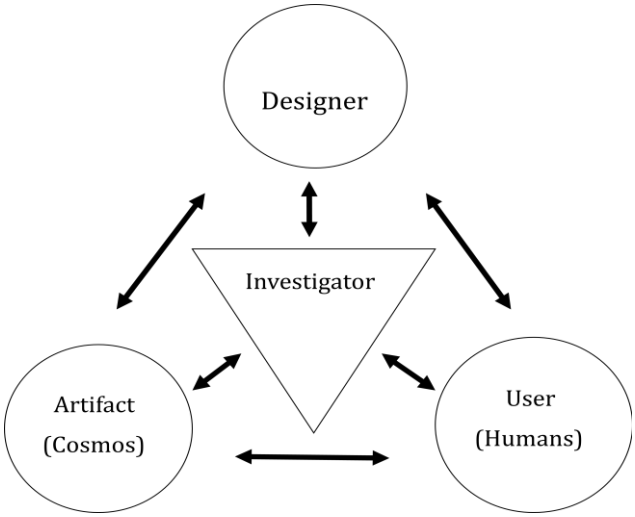

Figure 2. Reverse Engineering Potentially Involves Six Significant Relationships

Insight from Biology and Epigenetics

Recent discoveries in the field of epigenetics (the study of the chemical modification of specific genes or gene-associated proteins of an organism) may also shed some light on these issues. Multiple current research efforts have now demonstrated that certain animal behaviors can have significant detrimental effects on the genome of that animal, and even on its offspring and descendants.[22,23] It seems reasonable that this may also be the case with human beings. Indeed, research into the long-term effects of child abuse on human epigenetics has discovered various changes in brain chemistry associated with the abnormal behavioral events that may also be correlated to an increased risk of suicide.[24] In reverse engineering man-made systems that exhibit corruption or damage, it is often discovered that the system was placed in an environment or used in a way in which it was never intended. The Antikythera Mechanism was never intended to sit at the bottom of the sea, and the resulting corrosion and damage greatly prolonged the reverse engineering process. Consider how a screw driver is sometimes ill-advisedly used as a pry bar. Countless engineered products are damaged every year because they are used in a manner that would make the original design engineer cringe. The human child certainly was not designed to be treated inappropriately, but embedded into the design is the capacity to retain information from the experience and other environmental exposures, including nutrition,[25] to potentially adapt to changing conditions.

Maybe the corruption and damage we perceive in human beings is largely a result of the same kind of effect. If there is a Master Design Engineer for the human species, it is reasonable to conclude that humans were engineered for a particular purpose, or purposes. Furthermore, if humans stray from these purposes, it might be expected that they would experience corruption or damage. Romans 1:27 claims that the rebellious receive "in their own persons the due penalty of their error." However, it is the mark of a good engineer to offer a redemptive solution, taking what appears to be a negative development in the design process and "turning it around", causing

it to work for good. Historically, in engineering this has actually been called "making the devil work for you." This is a standard and documented part of creative problem-solving methods such as TRIZ (based on an extensive survey of the innovative features of patents).[26] Such "failures" are also recognized as an important, and perhaps necessary, part of creativity, and learning in general. In an intriguing collision between epigenetic and stem cell research,[27] continuing work with induced pluripotent stem cells demonstrates that in the presence of proper chemical or biological signals, cells can change their epigenetic profiles to return to a more "embryonic" state while continuing to retain memory of prior experiences.[28] It may be possible that the human design contains the potential to experience corruption and under the proper circumstances recover from the experience while gaining additional affordances.

Although the ways of a cosmic engineer would surely transcend human understanding of how to conduct engineering, as considered earlier, another traditional Judeo-Christian doctrine insists that humans are made in the image of God. This implies that we may have some small measure of God's creativity and problem-solving capability. In addition, God appears to reveal himself in categories that we, as humans, can understand. Throughout Scripture, he seems to encourage us to think of Him in those terms—even in terms of an engineer, or builder of a "spiritual house," as seen in 1 Peter 2:5.

Perhaps unbelieving scientists and engineers might find this line of thinking reasonable and suggestive of a preferable worldview. Missionary work is typically more successful if the message is communicated in the "language" of the target audience. In a sense, this approach attempts to speak the language of scientists and engineers. It takes the evidence with which they are largely familiar and weaves it into an explanatory tapestry.[29] In so doing, the evidence from science and engineering is found to play a key role in the cumulative case for a Christian worldview. [30, 31] The picture is one of an exceedingly competent and innovative transcendent engineer who is able to turn the messes of free-will beings into something good and beautiful if they will simply rely on their Maker and his redemptive plan through Jesus Christ. In so doing, corruption and death are consumed as all things are made new and caused to work together for good. As a result, many of the redeemed find that they are now particularly well-suited to minister to others in areas where they were once corrupted. This is just one example of how positive affordances appear to result from human corruption when placed in God's hands.

Another example is seen in how Christian character growth through adversity demonstrates that God's calculations are correct in allowing corruption to enter the system of life. In referring to the Thessalonians growing faith and love in the midst of suffering and adversity, Paul writes that "All this is evidence that God's judgment is right" (2 Thessalonians 1:5). In a recent article, professor Keith Miller agrees with this perspective as he writes, 'Natural "evil" thus seems to be a necessary component of the environment for "soul-making"…physical death, pain and suffering are opportunities for the expression of Christ-like character.'[32] He also claims that, "The issue of theodicy thus seems…to drive members of the scientific community away from a serious consideration of the claims of the Christian faith. The topic is important, not because its solution is central to the validity of the Christian faith, but because it often serves as an unnecessary stumbling block to a productive engagement of both science and faith."[33] It is hoped that these thoughts from the field of engineering may assist in removing this stumbling block. Perhaps then the skeptic will say with the Psalmist (Psalm 119:71-75),

> It was good for me to be afflicted
> so that I might learn your decrees.

The law from your mouth is more precious to me
than thousands of pieces of silver and gold.
Your hands made me and formed me;
give me understanding to learn your commands.
May those who fear you rejoice when they see me,
for I have put my hope in your word.
I know, LORD, that your laws are righteous,
and that in faithfulness you have afflicted me.

Conclusion

Affordance-based reverse engineering of natural systems with possible corruption provides a novel and fruitful approach to addressing the negative aspects of the human condition. Human corruption can actually result in positive affordances, if approached with humility and repentance. Examples demonstrate how reverse engineering of artificial systems lend insight into reverse engineering of natural systems. Further work is anticipated to explore the fruitfulness of this approach. It is hoped that affordance-based reverse engineering of natural systems will lead to a better understanding of such systems and the underlying negative factors associated with the human condition. It is also hoped that this approach will have apologetic and evangelistic value, especially among unbelieving scientists and engineers.

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