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**Designing for composites - traditional and future views.**
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## 1. The Advancement of Design Thinking

What visual and sensory signatures distinguish 'green' design principles?
And; what 'misplaced' imagery or features confuse or obscure these?

Achille Castiglione, the great Italian designer, has observed that aesthetics show you the *intention* of the designer. Our aesthetic response to objects, features and structures in our built environment is largely a matter of conditioning, and of a conditioned reaction to history. At a deep level aesthetic 'language' is a component of constructed meaning, and it is this constructed meaning which we experience alongside our actual sensory experience in the moment of using or encountering things. The work of the designer is that of combining the above challenges with the practical issues of material availabilities and properties, of manufacturing techniques, of creative and problem solving concepts, and with the many apparently conflicting pressures within the total picture of the business of product design.

This phenomenon makes it a difficult challenge to answer the question, 'what does ecologically responsible design look like?' sadly because we have little history with it. Difficult because the history of design is the history of repeated metaphors, of images and appearances copied from one era to the next in differing guises. Alternatively, if not copied, then reacted against. Reacting against something does not guarantee improvement, but rather just changing appearances, often leaving the underlying and flawed processes unaddressed. Old metaphors will not help us. The history of design imperatives has been, we now see, the history of narrow perspectives, of exploitation, and of grandiosity.

You would think that the eighteenth century orthodoxy regarding 'nature' i.e., a raw, immoral force to be subdued and contained, or where preferred, eliminated altogether, by burning, felling, killing, poisoning etc., would be an orthodoxy no longer in fashion. This convenient characterisation betrays the crudeness of those means of intervention available to people of that persuasion. The character of this mode of engagement with 'nature' is in keeping with the attitude that underpins it. That these activities continue largely unconstrained, not say actively promoted by some governments, is a shocking contradiction to any notion we may cherish that things are 'not as bad now'; we can see that the old stupid orthodoxy continues to actually underpin the actions involved in our 'use' of nature, despite all the talking-based developments of 'eco-awareness'. The debate is way ahead of the actions. We have been hearing about waste, about misuse of resources and about our dependence upon the living environment for the whole of our lives yet there is almost no action. Buckminster Fuller observed that an *important idea* for society took 25 years to register with people, and that a *really important* idea took 50 years. He said that in 1974 so it seems we have time yet.

It is time now, if ever, to notice the accuracy; the style; the fitness for purpose; the 'form follows function'; the drama; the delight; and above all the value systems in nature; to emulate them, to

profit from them, to be informed by them. It begins by noticing what is there. It has been shown that we see with our brains and our memory and ideas as much as we see with our eyes. Lets get our ideas shaping up to what we are looking at, when we look at natural examples.

In fact, Technology is giving us the tools to see these attributes of nature and to be so much less ignorant, but we have to change our thinking and our imperatives to truly see with these tools, otherwise we will continue only to see what we always have; that is, how to make a quick buck at someone else's expense; except now, the someone else is you and me. Just as we have the power to understand nature's materials in greater complexity, we will always be faced with the same choices- will it be 'slash and burn' but at nano scale? Will we really study at this level or simply subvert it before attempting to understand it? All spheres of knowledge present us with a blank canvas upon which to display our value system. In the material world our track record is not good.

In the present state of industrial consumption, it is time for a change in more than just the appearances of things. Thirty years ago the *Ecologist*[1] publication set out a 'Blueprint for Survival' and in 2002 the 30th anniversary edition of the same outlined many measures against which it could be established that conditions were significantly worse than in 1972. This, despite a number of notable 'advances' and isolated incidents of successful ecological improvement. However, bluntly, the main thrust of manufacture and consumption is unquestionably set for non-sustainability, and more significantly for *expansion* of the non-sustainable model in the 'developing' world. In contrast, natural systems have specialised in creating solutions, some defiant, some fantastical, some quiet and near invisible; all out of conflicting factors- there is no other way in nature. What can we learn from this?

One of the elementary exercises at beginning art school is to study drawing an object; say a stool, by drawing only 'everything-but' the stool – i.e., the shape of the spaces around the subject. This is a powerful method of developing genuine observation, relying as it does upon an *activity*. We think we are so familiar with the stool in everyday life that we tend to draw a stylised representation of something we already contain in memory, which process defeats the ability to observe and draw what in fact is in front of you in the present moment. In this sense, thinking only in symbols separates us from the subject and the present, connecting us instead only to a pre-existing attitude.

By analogy, the principle of this study technique applies to our research activities which must explore 'around' a subject in order to begin to understand the relational properties and the 'life' the subject has. In this way a more informed, less thoughtless design process can be supported. The significance of this concerning our conventional value system for materials is explored below; but what would be the obvious and stark result of applying this to everyday examples of contemporary materials consumption, in an attempt to establish a conceptual framework that could lead us towards a more life-supporting value system regarding materials?

## Three Principles of Development

Now that we are developing the technology to design composite material properties across the entire spectrum from nano- to micro- to macro- scale, in terms of fabrication and assembly

techniques, we have less excuse to fail to address the key challenges of conventional production, namely;

• NO WASTE ; a discipline applied at all stages of design, appraisal, manufacture, use, re-use-recycling and disposal

• ENVIRONMENT CONSIDERED AT EVERY STAGE (constraints observable from living processes)

• "VALUABLE" as a term has to gain a REVISED DEFINITION;
*Old definition;* = rare, exotic, not easy to obtain, special, prized, trade gains, kill to get it.
*New definition;* = preserves or enhances the environment, and life processes.

Attempting to apply these concepts and deal with the consequences will surely produce the conflict with our present knowledge framework that is required to jump-start creativity, utilise our senses and map out the response space available to us.

**An Obsolete Value System**

Despite a generation of commentary and research to the contrary, we remain stuck with the obsolete value system when it comes to the manufacture and distribution of materials, products and produce. The exotic material fixation that is a leftover of empire remains to this day. The working philosophy of "Think Global – Act Local" has hardly begun to make an impact. Much eco-marketing cynically manipulates that genuine interest that exists in the public sphere, in order to continue the old polluting or poisoning processes for maximum profit. What Profit? Here is the remarkable paradox, where in an isolated value system the term 'valuable' applies to short-term money within a rigged gameplan, ignoring all the attendant consequences. Here is where money is valued more than the environment. The balance sheet looks good because of all the actual, 'real world' consequences whose value or significance has been discounted, and whose destructive and uncontrollable effects are ignored or excused by an increasingly self-absorbed value system. Something can be regarded as 'too expensive' in this scheme – because it is being compared to something detached from the actual ecosystem, for the convenience of managing a process within an outdated set of parameters. The very process of 'birthing'- of life creation within natural energy systems, is being noticeably curtailed within this business model.

It is a contemporary phenomenon that metaphors of progress sourced from the rapid changes in manufacturing processes since the nineteenth century are now generally applied, quite uncritically, across most social and working situations. Much misery and stress among employees and users is created by these means. It is not only the environment that suffers from our present manufacturing ethos. Its' very underpinning philosophy is capable of subverting our thinking. 'Doing more with less' is a great idea when applied to improvements in the rate at which a certain product can be turned out. But the metaphor fails when applied to say, a Beethoven string quartet. It took four people and 41 minutes to produce in 1826, the same in 1958, and no doubt will be much the same in 2014. The string quartet in question[2] reached a steady state of technological development, and no amount of innovation or creativity will bring about a condition

in which 2.8 people can do the same job in 13 minutes. Metaphors are evidently inescapable in the language of research, but knowing where they do, and where they do not, apply is remarkably challenging. "Prolonged Empathetic Study" as described by Goethe[3] is necessary.

For lessons in 'what is valuable' or 'how expensive' something is, we need to study natural processes. Natural processes of fabrication of substance, of components, of structures, are all *responsive,* i.e., there are relational properties at play in the varying factors of the environment affecting the resulting patterns, formations, shapes, and compositional factors. This can be seen as having a consequence for each of the 'principles' above; (no waste, relate to environment, local available resources support life.) Secondly, as established by Goethe through his principle of 'prolonged empathetic study' there is both an appropriate time-line for all life processes, and a patterned set of adjacent phenomena without which an understanding of the subject is not possible. An intelligent study takes these formation and de-formation sequences and dynamic contexts as characteristics of the research process, which must 'track' these characteristics in order to question our experience associated with them. The 'subject' is seen more as process made up of characteristic stages, not a conceptual snapshot of an object in isolation from such a process or 'fate'. A leaf is a good example of this principle. A real leaf is an adventure of changing form, changing process, of response to harsh conditions and to damage and attack, of aerodynamics and thermal control, of chemistry and physics, of deployment and retraction, of disposability and recycling, even of environmental roles for other life forms after its connection with the tree is ended. Natural systems are multi-purpose. Does its connection with the tree ever end? Does the tree leave the leaves or do the leaves leave the tree?

The history of the making of 'things' has given us all too often a preoccupation with the object itself – its style, identity and possession of it, rather than its role in a continuing narrative. The implication is that of independent existence; i.e., (the business plan) is constructed in a manner devoid of any connection with life processes, and fits perfectly the desire for 'identity' to be captured within the unique purchasable product. This could be seen as the endgame of the Victorian notion of nature as 'foreign' to the rightly minded person; now clearly an essentially vain construct. One of the main features of this, and an indication of just how archaic this value system is, is the notion that what was once the preserve of the royal figurehead, over the generations of admiring the royal possessions; that society must be getting better now that we can *all* have those things. Thus the 'exotic' artefact, by way of ever more crude iterations, becomes the ubiquitous possession. The royal beneficence flows down the cascade of society, enriching all. Further than this, now that brand image itself has been established as a 'virtual' attribute, devoid of material substance, it is possible to coerce individuals and groups into purchasing literally nothing, yet continue to generate pollution and waste in the process. Any beneficial content that was supposed to be present in this trading system has become a chimera, despite that the burden of waste upon life processes continues in no less real a manner than at any time previously. What a remarkable transformation in the meaning of the term 'industry' this is.

The appalling consequences of the narrative that has unfolded from this outdated and unthinking value system is only now impinging upon our consciousness. The waste computer mountains in China, the daily barges of post-consumer waste queuing to escape Manhattan island en route for the ocean, to make space for more 'pound-shop' produce, the increasing familiarity with the term 'landfill' in our news; you cannot miss it. When you think of the term 'landfill', what effect does it

have upon you? >LAND-FILL<. The bizarre phenomenon of the disposable drink container that lasts longer than a house yet has 18 seconds of primary use; if nothing else, could make you wonder what we could achieve if we concentrated on a conceptual picture for product design that included all the players and their timeline in a more integrated scenario.

**The Big Challenge**

The big challenge for designers concerning contemporary imperatives in material consumption, utilisation and innovation, is that a century of attitudes towards materials- the 'exotic' the 'rare' the 'special' – (epithets that belong to an age of exploitation and vanity, with attempts to emulate royalty, conquest, etc.,) has left us with an inappropriate vocabulary for contemporary material science. The easy reiteration of accepted orthodoxy, i.e., to do what we did before but do it faster, while being one of the features of computer aided manufacture, is not the feature we are bound to adopt. The choice is ours.

In a now dated yet significant critique of overly contrived ordering in city life, author Richard Sennett (in *The uses of Disorder*[4]) makes a significant observation about the differing relationships possible between ourselves and the materials we use;

*[quote]* 'In pre-industrial workshop production systems, the *experience of making* a product was more important than a predetermined standard image of the "whole" to be made. These craftsmen conceived that to define in advance what a thing should look like would interfere with their notion of 'efficiency', that is, with the freedom of the craftsman to exploit the materials and forms *during* the making process. In an industrial situation the product to be made is conceived beforehand so that its realisation is a passive routine, not an active experience of exploration'. *(My italics-CR)*

An 'active experience of exploration' is just exactly what is required now with new material alternatives, materials which do not arrest living processes, do not poison the air, the water and the ground, and do not subvert life processes irreversibly.

Our present state of working with 'green' composite materials parallels in some respects the nature of those craft processes that drove innovation in the industrial revolution. The application of complex new materials and their translation into new components and products requires a slow, studied and skilful engagement of the new generation of materials 'craftspeople'. We are at a decisive stage of 'reflective practice' again, where material possibilities extend beyond previous experience, references and conceptual metaphors. The circumstance is analogous to the period in which cast iron structures were being designed based upon the carpentry techniques of prior experience. Despite all the conceptual baggage associated with this approach, it was the only available platform from which to extend into new material territory. Those craft skills and interpretations, by being stretched and challenged, provided the literal bridge into what became new material territory, bringing with it new forms, new methods, new structures, new products and new environments.

We can be certain that a distinctive cultural and aesthetic language will emerge from an understanding of the applications and consequences of intelligently formed materials. However it

will not emerge from a theoretical position but from a series of actions and events in society. If ecological responsibility is to revalue what is local, and to understand the web of relational properties that must inform responsible design, manufacturing and consumption, and indeed living properties themselves, this new aesthetic language needs stimulating in order to create a place in consumers' understanding for these new materials. This has to go beyond the use of carbon-fiber look-alike decals that make the things they are stuck to look 'technical', or the overprinting of eco-fashion unbleached colors onto conventional bleached paper to trick the consumer. Polite home-style labelling is no guarantee of home cooking.

This major challenge in materials intelligence lies equally in the realms of design, marketing, manufacture, information, distribution, retailing and waste control. Why would a biodegradable product be convincingly seen as superior to its energy-inefficient and polluting predecessor? How will a material that respects life processes be perceived as truly 'valuable'. Lets apply those three principles; 1; No Waste. 2; Environment Considered at Every Stage. 3; Redefine the Term 'Value' in terms of life support. How do products 'speak' about creation and destruction- about living processes and intelligent design? It would be a mistake to regard these issues as only applicable to luxury goods or the retail mall, or to imagine they can only be tinkered with at the margins of society. The value system that brings us this apocalyptic picture of waste, short-term thinking and abuse of the living environment continues to pervade the majority of manufacturing and materials consumption in its various spheres of influence. Whilst there are examples to be found of top-down and bottom-up environmental intelligence in contemporary business organisation, the twenty-year window of opportunity for sustainable values so comprehensively described by Paul Hawken[5] in *The Ecology of Commerce* in 1993 has not been realised.

As a designer, I have to look to nature to try and find the departure points to help with this.

## 2 How to think about composite materials

In an attempt to begin to answer some of the questions posed above we can look at the relationships between material nature and 'formal' design (i.e., the form things take) and understand more about the paradigms of the natural examples we choose.
Following is a list of a few observable visual aspects of the physical formations and patterns that are characteristic of natural material engineering. Rather than provide illustrations, which could fall into the trap described above of drawing the stool, the reader will hopefully recall in memory those features that are recognisable to you, and be able to add some of your own. This kind of memory tends be 'holographic' in nature and so inherently richer than selective line drawings allow. Making your own drawings of these and other such features is a potent tool for appreciating key principles. The natural material world is full of 'self-illustrating' phenomena, and we are surrounded by source material for such study. The word list is intended as a provocation and a starting point.

The key questions are; why are they like that? How do material properties relate to the shapes of surfaces, of components, and of substructures?

Network construction (bird nest, leaf, web)

Blending of forms avoids abrupt transition of shapes (bones, branch, wing)
Abrupt transitions in shape accompanied by local thickening or other reinforcement
Proper location of openings (crab shell, skin structures, bodyforms)
Apertures, fixing points, projections, to spread load (pelvis, skull, basket design)
Interface issues; differential properties arranged in three dimensions to accommodate complex characteristics (tendon, spider web, foot)
Volume; skin; strut; cell (e.g., water retaining structures in plants, 'vessel' forms and vessel containment)
Corrugation; the zone between two dimensions and three
Profiles; harmonic shapes, moiré patterns
Stem-branch relations
Swelling of forms; exterior / interior relations
Curvature; simple and compound
Braiding, twisting, binding
Thick edges, thin films
Doming; compression and tension in domed forms
Stem and plane (support structures for surfaces)
Perforation
Twisting of plane shapes
Orientation of fibers, layers of fiber orientations, simple and complex
Combination different fiber materials; combining of properties
Fibers following forms, skirting holes or point loads
Fiber - matrix relation (rationing of)
Granulation, granular networks
Inclusion of locator or bearing components; contrast materials
Modification of form or material at fixing points
Different density/particle structure; properties across section
Outer and inner forms relate to material properties
"Product architecture"; structural metaphors ('modular', 'frame', 'clamshell', 'skeleton' etc,) help us conceptualise the principles of our design.

A useful formal metaphor for composite sheet material or surface materials for example is that of drapery, or fabric forms that are 'frozen'. Other such relationships with our common experience can be useful in studying natural materials.

Here are six images that give some examples of opportunities to learn from natural material structure, in which the visible shapes, not only of the object but of surface detail and texture, and structural features, display some of the 'signature' shapes of essential functional attributes from the short listing above.

******insert 6 x  illustrations below [Jpeg or Tiff images supplied by Chris Rose]******

caption 1 >Leaf networks; repetition and diversity. This type of recognisable pattern has that special combination of fluid variation on a theme that is key to natural systems. It is pleasing aesthetically because it suggests movement and rhythm without being coldly repetitious.<
tiff file title; leaf networks 1

caption 2 >Basket made by Jenny Crisp (UK). Natural material aesthetics. The fibrous structure of the willow can be highly distorted whilst still retaining sufficient integrity. The design of the whole basket has to define edges and volumes with differing techniques, analogous to the sophistication of natural engineering.
tiff file title ; baskets-Jenny Crisp 2

caption 3 >Crabshell Architecture; inner complexity. Very light inner 3-D network of compartmented forms developing from the outer shell significantly improves damage control of the whole while providing an interface for inner organic structures.<
tiff file title; crabshell architecture 3

caption 4 >Crabshell Edge; where it gets vunerable. The open rolled edge is resistant to impact, defines the form, (the form that we recognise) and provides location for contrasting tissue structures. Edges are always vunerable. Many natural structures avoid them or make them multiple.<
tiff file title; crabshell edge 4

caption 5 >Palmleaf packaging; natural food wrapper. Corrugation folds extra length into the apparent surface and retains complex flexibilities, allowing the enclosed volume to be variable, and for the very challenging distortion of the 2-D surface into the 3-D form. Where are the edges?<
tiff file title; palm leaf packaging 5

caption 6> Lessons in design; multipurpose structure of cactus 'skeleton'. 3-D corrugation, perforation and 'braiding' of outer shape, provides a characteristic organisational definition of the whole structure and its living processes. Clockwise and anticlockwise spirals at differing slopes are typical, giving a formal 'bias'.<
tiff file title; cactus skeleton 6

All photographs by Chris Rose

## 3 'High Technology is Not New'

Designing and using composite materials has been the principal manner of making functional products for millennia. Restricted to natural materials, tremendous sophistication and technical expertise characterise much indigenous and pre-industrial object making, developing as it has over many generations who evolved, refined and perfected designs into what could be termed a 'stable' technology. From Inuit clothing based on the assembly of skins, through the Tudor oak framed house in England which gets tougher with every passing decade, the bushman recycled eggshell water-carrier and the composite longbow combining those properties of bone and wood that can cope with extremes of energy storage and release; Physical struggle with the myriad material properties of available materials was the only research method available, and examples of these artefacts are prized as collectable products redolent of human connection with nature. Such material sophistication was not however limited to reworking organic materials. The bronze

casting technology of Benin in the sixteenth and seventeenth centuries has never been bettered. The fact that this advanced science, its location and practitioners, did not comfortably fit with a colonial world view led to attempts to suppress, destroy or intellectually marginalise its significance; a phenomenon only partially redressed by 20thC scholarship. Echoes of such techno-imperialism deeply affect us today in the value systems attributed to various 'classes' of product, often blinding us to the sophistication inherent in certain traditional 'evolved' designs. The conventional styling associated with many 'modern' products has no connection with objective measures of genuine sophistication of material and method.

Certain ancient Egyptian chariot wheels combine heat-formed wood laminated and bound with skin, making a tough and resilient composite and biodegradable vehicle part three thousand years ago. Some of the earliest middle-eastern engineering feats utilised wood and fiber constructions in the form of giant water wheels (*noria*) for irrigation, extending the reach of wood ('natures fiberglass') into massive components that were up to a difficult task. Possibly the most iconic of all structural forms- that of the upright bound papyrus column- not only survives its many reinterpretations to the present day, (a phenomenon that has been ascribed by some writers to Brunelleschi's studies in Egypt) but is in itself an object lesson in design for composite materials, combining as it does both outer and inner form and the multiplying factor of smaller elements.

Different 'forms' (shapes) can reference a variety of recognisable principles- from the cultural icon to the structurally prototypical. Design practice explores this multiplicity of 'visual language' and renews or reinterprets the familiar, dealing with issues of appropriateness, interpretation and use. The '*bundle*' form, of which the column is a notable architectural example, appears everywhere from ancient ocean-going rafts, through the cast iron connecting rods of industrial revolution machines to the protective chrysalis enclosing emergent life in nature. In my view this 'form' therefore merits study in any consideration of materials, their behaviours and preferences. *Water* has a preference for 'going globular'. Goethe considered that the physical forms of plants, composed largely of water, showed a preference for embodying the tendency of water to generate fern-shaped turbulent flow vortices when disturbed. Further study of these 'Flowforms[6]' is highly relevant to new applications for certain composites and their manufacture- not only in terms of mechanical processing but in terms of material formation, biomimetic properties etc.
Since our technical ability to model and visualise in three dimensions complex mathematics such as flow, pressure gradients, intricate networks etc., has become generally accessible in the last ten years, we have the tools to match up two powerful processes in our understanding, namely; 1/ our ability to recognise 'complexity' because of our human interest in pattern and our lifelong experience in reading such patterns in our sensory and social environment, and 2/ the ability to arrest, simulate and visualise the patterns of complex structures and model their various attributes as part of design processes that go 'below the surface' and potentially encompass differing scales from micro to macro in an integrated approach closer to the engineering of nature. From composite molecular design to composite buildings, the sophistication of future structures, products and materials holds out a promise as impressive, and as dangerous, as the longbow.

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Endnotes; referred to in text

[1] The Ecologist; "Blueprint for Survival" 1972 and Vol. 32 No.7 2002 www.theecologist.org

[2] Beethoven Late String Quartets Op.132 1825-27

[3] See *Goethe's Way of Science, a phenomenology of nature;* Seamon, David and Zajonc, Arthur State University of New York press, 1998

[4] Sennett, Richard *The Uses of Disorder* Pelican Books 1973

[5] Hawken, Paul *The Ecology of Commerce: a Declaration of Sustainability* HarpurCollins 1993

[6] Wilkes, John *Flowforms, The Rhythmic Power of Water* Floris Books 2003

Selected further reading and sources of information;


• *Lightness; The Inevitable Renaissance of Minimum Energy Structures* Beukers, Adriaan; van Hinte, Ed 010 publishers Rotterdam 2001

• *Design Engineering* Rose, Christopher et al; Butterworth Heinemann 2001. See chapter on 'Creative Design Practice'.

• ITDG (Intermediate Technology Development Group) London. Extensive publication list.

• Fourth Door Review; 'a green cultural review for the twenty-first century'. www.fouthdoor.co.uk


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