HETEROGENEOUS MATERIALS AND VARIABLE BEHAVIOUR: POTENTIALS FOR THE DESIGN DISCIPLINES

BY MICHAEL U. HENSEL
AHO - OSLO SCHOOL FOR ARCHITECTURE AND DESIGN
OSLO, NORWAY
TEL: +47 9832 2210
Michael.Hensel@aho.no

In the design and use of human-made artefacts materials play a central role with regards to appearance and functionality. The performative capacity of a design is actualised through materiality. However, while architecture is a material practice, highly specific materials with carefully defined characteristics and properties are often chosen late in the design process. Moreover, often a materials response to extrinsic stimuli is regarded as negative. All sorts of measures are taken to neutralise such responses. In contrast, however, there is a growing fascination with 'smart' materials that can respond in controlled ways to extrinsic stimuli. If the definition of smart materials would be employed to embrace defined capacities in ordinary materials this may yield an fundamental rethinking of both the performative capacities of human made artefacts and the design disciplines. This paper aims therefore at discussing material capacities and variable behaviour as a potential for rethinking design and sustainability.

INTRODUCTION

A lot has been written about materials by and for designers. These writings can generally be categorised as picture-based material catalogues for designers or data-rich technical books. Yet, architectural design rarely commences from a highly specific material selection, and an instrumental deployment of material properties and behaviour, as the necessary empirical studies needed for this are considered not feasible. Architects are typically more comfortable with defining tasks and delivering a designed / engineered solution and not entirely comfortable with finding opportunistic applications for given material capacities. Material is thus too often treated as a solution instead of a potential.

Today many authors often celebrate ‘new’, ‘smart’, ‘responsive’ or other such labelled materials. (i.e. Ball, 1997) However,as Philip Ball stated: ‘In the past, a change in a material’s properties in response to a change in the environment was generally seen as a potential problem, as a thing to be avoided’. (Ball, 1997:104) The recent fascination with so-called ‘smart’ and ‘responsive’ materials attest to an opposite trend, the embracing of the ability of engineered materials to deliver controlled change and variability in response to environmental stimuli. Yet, are all existing materials ‘dumb’ in comparison?

Smart materials are usually defined as ‘highly engineered materials that respond intelligently to their environment’. (Addington and Schodek, 2005:1) Philip Ball offered another interesting definition: ‘Smart materials can be thought of as materials that replace machines – in other words, materials that can carry out tasks not as a consequence of signals or impulses passed from one component to another, as the transmission of a car passes the power of an engine to the wheels, but as a result of their intrinsic properties'. (Ball, 1997:103) Furthermore, Ball states that 'some materials may simply be smart enough to respond each time [to] a particular characteristic of their surroundings (such as temperature or pressure) changes. But others can be envisioned that get wise to such changes, that maintain a memory of what has transpired before and that learn from these previous experiences'. (Ball, 1997:104) Natural materials, are characterised by a kind of embedded memory that is superior to engineered materials that can 'memorize' only over their specific material lifespan and be used in a defined relation with specific environmental stimuli.

Philip Ball continues that 'perhaps the greatest value of natural materials does not lie with their "naturalness" in itself but in their potential to serve as models for the advanced materials of the future'. (Ball, 1997:144). The question arises then, whether we can first rethink our position towards the materials we have at hand, reconsidering their properties and capacities for 'responding intelligently to their environment', before we embark on the design of new materials, in order to add to the scope. An interesting possibility would be to alter designed material properties according to need and in-situ; however, before we go there, we might consider making more from what we already have available to us. In this regard Philip Ball posited that 'today we still do not have a material that rivals wood in its subtlety of structure and property. (Ball, 1997:)

MATERIAL PROPERTIES AND BEHAVIOUR

Material can be categorised according to different intrinsic or extrinsic properties. While the former result from the molecular structure of a material the latter result from its macro-structure. Addington and Schodek posit that 'all material properties, whether intrinsic or extrinsic, smart or "dumb" fall into one or more of five categories. The categories – mechanical, thermal, electrical, chemical and optical – are indicative of the energy stimuli that every material must respond to … All energy stimuli are the result of "difference". A difference in temperature that produces heat, a difference in pressure that produces mechanical work. Properties are what mediate that difference'. (Addington and Schodek, 2005:39) Addington and Schodek continue that 'for physicists [...] the boundary is not a thing, but an action. Environments are understood as energy fields, and the [material] boundary operates as the transitional zone between different states of an energy field … Boundaries are therefore, by definition, active zones of mediation rather than of delineation' and 'breaking the paradigm of the hegemonic "materials as visual artefacts" requires that we invert our thinking; rather than visualising the end result, we need to imagine the transformative actions and interactions'. (Addington and Schodek, 2005:7) What is interesting here is that materials are characterised by the way they respond to stimuli that emanate from a specific given environment, and by properties that are intrinsically related to behaviour. Also of interest is that the shift in the understanding of the material / environment boundary from delinating threshold to gradient field of interaction, also extends the understanding of the material artefact to a milieu of conditions and effects. This delivers one of the key potentials in redefining how one might relate to artefacts and yields fundamental changes in what might be the key concerns of design itself. What is worth noting, however, is that Addington and Schodek do not include biological properties in their definition. In order to tap into the performative capacity of biological materials, such as wood, we will need to look for additional concepts and definitions.

Julian Vincent posited that 'all material has structure … it turns out that you can disregard the structure and treat the material as homogenous if the structure is small enough in comparison to the size of piece you are investigating. To some extend the dividing line between material and structure is therefore difficult to define – more so for a biological material that is complex at many levels of size'. (Vincent, 2006:47) This becomes immediately relevant when related to Werner Nachtigall's description of the properties of plant fibre composite materials: '"Traditional" technical constructs are generally optimised with regards to material, yet, only marginally structurally optimised. This is entirely different for biological systems, since plants have only a small number of "construction materials" available […] Based on these materials there emerged in the course of evolution highly structurally optimised biological systems, which generally have to provide for multiple functions: Multiple-objective Optimisation'. (Nachtigall, 2002:81. Authors translation). Biological systems are able to perform in ways that are quite different from typical technical constructs. They are characterised by a higher-level functionality that we shall refer to as 'performative capacity'. At any rate there can be simultaneous stimulus-response relations in exchange with a specific given environment that result in a mileu of effects, except that we must now extend this notion to a heterogeneous milieu of effects. Julian Vincent posits this relation in a different way: 'Local quality – change the structure from homogeneous to heterogeneous, change an external environment from homogenous to heterogeneous, make each part of an object function in conditions most suitable for its operation, or allow each part of an object a different function'. (Vincent, 2006/2: 227) Initially it seems contradictory that biological systems should be able to fullfill multiple functions, while its 'parts' should be functionally specific. Moreover, the material build-up of biological systems is not suited for a division into component parts, as the transition between one region and another is generally some form of gradient. The transition from tendon to bone, for instance, is based on the exact same material with a different degree of calcification, which gradually increases from tendon to bone. It is therefore often not possible to identify a dividing line between regions. Although, there is, of course, on a cellular level inherent unity of cells that are separated from their exterior by means of a cell wall, which clearly indicates the presence of specific harder thresholds and divisions.

In his definition of biological composite materials Nachtigall resolves the dilemma between multi-functionality and functional specificity: 'biological composite materials are generally hierarchically structured. This implies that they are composed of items that constitute functional subsystems. A larger number establish a higher-level system etc, and so it continues from the molecular level to the macroscopic biological systems'. (Nachtigall, 2002:58. Authors translation) Biological systems are often articulated over eight scales of magnitude. It is clear that there are very many subsystems-levels that constitute the overall biological system. While specialisation might characterise the overall system at the 'element' or subsystem-level, the heteregeneous set of subsystems yields the multifunctional or performative capacity of higher-level subsystems and the overall system.

We shall proceed by examining some promising material properties. Isotropic materials are homogeneous in all directions, while anisotropy is the property of being directionally dependent. It can be defined as a difference in a physical property for some material when measured along different axes. Fibrous materials such as wood are naturally anisotropic materials. Their properties vary widely when measure with the growth grain or against it. Biological fibre materials aquire their anisotropy, that is their fibre directionality in response to stress direction. This is indeed a desirable characteristic since extrinsic input, such as stress and intrinsic material articulation are thus finely calibrated. However, the response to many extrinsic factors also leads to variable articulation of the intrinsic material makeup. Therefore biological materials such as wood are often seen as flawed, as specific cuts from a trunk or branch of a tree will vary in their internal makeup. Matters become more complex when hygroscopy is added to anisotropy. Hygroscopy entails the ability of a material to uptake water molecules from the environment. Wood is hygroscopic and can therefore absorb moisture from the environment or yield it back, 'thereby attaining a moisture content which is in equilibrium with the water vapour pressure of the surrounding atmosphere'. (Dinwoodie, 2000:49) Hygroscopy coupled with anisotropy leads to dimensional variability of the material. In other words, the material can swell or shrink, that is elongate or shorten in response to the relative humidity of the environment. With regards to dimensional instability it is important to distinguish between 'those changes that occur when green timber is dried to very low moisture contents, and those that arise in timber of low moisture content due to seasonal or daily changes in the relative humidity of the surrounding atmosphere. The former changes are called "shrinkage", wheras the latter are known as "movement"'. (Dinwoodie, 2000:58) Both types could be utilised the same way the response of a 'smart' material is utilised with regards to its capacity to correspond to a specifically chosen stimulus. Instead of a technical array of sensor, translator and actuator these capacities are already embedded with the material. This may inform either a different use of wood with regards to its variable behaviour and related performative capacity, or, instead, the strategic design of an anisotropic and hygroscopic fibre-reinforced polymer composite material.

Material differentiation is not exhausted with anisotropy. Relative to wood density and growth rate are important variables and so is what is known as reaction wood. Barnet and Jeronimidis describe the latter as follows: 'Unlike young stems and shoots, which are still undergoing elongation growth and can therefore maintain or change their orientation by differential longitudinal growth, woody stems have ceased elongation and must correct their orientation by bending the existing structure (Wardrop, 1964). They do so by producing modified wood known as reaction wood. The anatomy, structure and physical properties of reaction wood are adapted to provide the required biomechanical function'. (Barnett and Jeronimidis, 2003:118) Such level of internal differentiation is, however, still universally seen as problematic. This becomes apparent in the evaluation of reaction wood by Barnett and Jeronimidis, both eminent experts in biomimetics: 'The main problem associated with quality and utilisation of wood and timber containing reaction tissue is the fact that their shrinkage characteristics are different from those of adjacent normal wood […] since reaction wood is typically localised on one side of the trunk and is often found only in a proportion of the total number of annual rings, it leads to differential shrinkage effects during drying. These manifest themsleves as warping, twisting, bending and cracking …'. (Barnett and Jeronimidis, 2003:133) Barnett and Jeronimidis conclude that 'important, however, may be understanding and eliminating the apparently unnecessary formation of reaction wood in fast-growing trees'. (Barnett and Jeronimidis, 2003:134) It comes with surprise that biomimetics experts should choose to fall back into the established position of eliminating differentiation due to entrenched industrial prejudice pertaining to what is useful or feasible and what is not. It would seem that material differentiation with the ability to respond in a variable manner to extrinsic stimuli would be the current holy grail of 'smart' material research and development. Nevertheless, it is the case that the main thrust of wood products development, for instance, pursues the opposite direction, namely that of producing laminates or other sorts of products that aim at entirely undoing the effects of internal differentiation of the material. Other products go deeper with changing the cellular characteristics of wood to accomplish products with novel charcateristics. In any case it seems chiefly counterintuitive and not exactely feasible to attempt the wholesome modification of material characteristics and properties to suit industrial prejudice, instead of utilising such features.

CONCLUSION

This paper aimed at discussing heterogeneous materials with variable behaviour and the undeserved entrenched prejudices against these. While a lot of research is directed towards the making of 'smart' materials, not enough attention is paid to understanding and deploying existing materials in a likewise manner. To deploy the performative capacity of a lesser number of materials, aims for greater sustainability with regards to the problem of sparse resources. In addition nature teaches us that a lesser amount of materials used to accomplish a higher level of performative capacity, may help with regards to the ease of recycling, especially when these materials are biodegradable. The aim was to show the inherent capacities of such materials and highlights that such capacities can be utilised in an opportunistic manner. However, the paper is not understood as a design manual and thus does not list any direct applications. Much more research is required to move into that direction. A master-level studio and themed course at AHO in the Fall semester 2009 and Spring semester 2010 will investigate the design potential found in the material heterogeneity of wood. At any rate, such research will hopefully contribute to shifting the sensibility of understanding and conceiving material artefacts and their related milieu of effects.

REFERENCES

Addington M. and Schodek D. 2005. *Smart Materials and Technologies for the Architecture and Design Professions*. Oxford: Elsevier, Architectural Press.

Ball P. 1997. *Made to Measure: New Materials for the 21st Century*. Princeton: Princeton University Press.

Barnett J. R. and Jeronimidis G. 2003. 'Reaction Wood'. *Wood Quality and its Biological Basis*. London: Blackwell. Pp. 118-136.

Dinwoodie J. M. 2000. *Timber: Its Nature and Behaviour*. 2nd Edition. London, New York: E&FN Spon.

Nachtigall W. 2002. *Bionik: Grundlagen und Beispiele für Ingenieure und Naturwissenschaftler*. 2nd Edition. Berlin, London, New York: Springer.

Vincent J. F. V. 2006. 'Making a Mechanical Organism'. *Journal of Bionic Engineering* 3:2006. Elsevier Scientific Press. pp. 43-58.

Vincent J. F. V. 2006/2. 'The Materials Revolution'. *Journal of Bionic Engineering* 3:2006. Elsevier Scientific Press. pp. 217-234.

Wardrop A. B. 1964. 'The Reaction Anatomy of Arborescent Angiosperms'. The Formation of Wood in Forest Trees. New York: academic Press. pp. 405-456.