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PARAMETRIC MATERIALITY

Material properties as catalyst for design

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Abstract. Sustainability issues are increasingly taking more prominent positions in the hierarchy of design decisions. The combination of linked digital analysis and parametric design has emerged as an integrated method of assimilating performative characteristics into design. As these "informed design" methods evolve there is an increasing ability for architectural geometry to be rationalized, whether this is for reasons of constructive optimization, or environmental and economic justification. But the macro scale approach to geometry in design is only one mediator of the designs impact in its surroundings. This paper discusses what happens when designers fundamentally question the role of materials in design, and specifically what happens when "new" materials and their performative characteristics can be modelled and implemented into the digital design decision process. These approaches are showcased in "proof of concept" projects that have been developed using digital design and production technologies, in collaboration with material scientists and industry.

Keywords. Materiality; analysis; performance; design; fabrication

1. Introduction

Architects are continually faced with the fact that successful work is dependent on their ability to engage with a vast array of subjective, programmatic, situational and environmental variables. It is this professional setting which drives the need for architectural innovation. Within the current context, issues of performance and sustainability are becoming increasingly important; both in terms of the social and environmental responsibility of the practitioner, but also as imposed regulation in building and performance codes.

To address the increasing demands for *sustainable* design we first need to define the term specifically. For this paper we will adopt the 2005 UN definition that states that "something is sustainable if it improves the quality of human life while having a neutral or net positive effect on the carrying capacity of supporting eco-systems". This definition is both interesting and important for architects and designers, as it shifts the emphasis of the definition onto the issue of *quality of life*, and away from the traditional and strict objective measures of energy, resource use, carbon, and pollution.

2. New justifications

In the current social, economic, and environmental context, there is an increasing requirement for sustainable buildings and urban design. Solutions for performance are becoming more and more dependent upon precision of interventions and detailed understanding of cause and effect within design proposals. However, architecture and urban design solutions typically develop in a top down manner, working from abstract representations of a problem, then, progressively detailing a solution. If a system is only understood at an abstract level, then a solution will also address only this; if a problem is understood at a detailed level, then the solution will be comprehensive. For architects to improve their own influence on the built environment, they need to understand problems and solutions at a detailed level.

The research profiled in this paper addresses this by inverting the normal progression of architectural design, to begin design at the detailed level of materiality. Our experimentation begins with a detailed understanding of a material, and then develops design suited to the material and its performative characteristics, all in relation to a project brief. To emphasize this approach the research is being conducted using "new" innovative material technologies which have multi-purpose performative characteristics.

3. New requirements

Material properties play a significant role in the decision hierarchy of all physical designs. For industries where the aim is to produce a physical product - be it a computer chip or a skyscraper - materiality and the characteristics of *matter* provide the substantive basis for physical character. As digital tools are used to search for more efficiency, performance, and greater design expression; there is an irony that materiality is re-emerging in importance.

The incorporation of *material* data into parametric design is problematic. Material value is often characterized by subjective or qualitative characteristics, and as such these values do not "fit" into the objective use of programming as a design medium.

When material values can be objectively compiled in such a way as to allow for computation, scripted geometry can be used to create feedback loops that allow for optimization of specific goals. Digital analysis and evaluation scripts are increasingly being used to align materiality with digital geometry, and then with digitally controlled fabrication.

Scientific developments have invented new materials that are suitable for architecture and construction which are imbued with performative qualities. If these qualities can be integrated in digital analysis and design, then the feedback between geometry and performance characteristics becomes more complex, more detailed, and more architecturally interesting.

3. New interactions

There are three main areas of our research in which we have engaged performative material characteristics: *structural interactions, chemical interactions,* and *fabrication interactions*.

Structural interactions is the largest scale of material interaction, it is the combination of variable material characteristics with designed geometry. Materials are being engineered where the structural properties change based on external physical influences. Structurally adaptive materials include composites which become stiffer when exposed to vibrations, materials which become stronger when subjected to changes in temperature, or materials which become more elastic when exposed to specific noise frequencies.

Fabricative interaction materials are materials which are individually designed and then fabricated to have very specific and customized performance characteristics. Composites of this type are already used extensively in design, especially material compositions of fibres/textiles and metals/alloys. New fabricative methods for refining materials at smaller scales are increasingly being developed, and architects are already using materials that have been developed for scientific needs, only to be “re-used” for mass markets.

Chemically interactive materials are imbued with chemical or catalytic properties so as to have specifically controlled reactions with other reagents. The main realm for chemically interactive materials in architecture is in coatings, paints, and additives for concrete. Chemically interactive materials are developed to react with their surrounding environment, changing the chemical nature of their context, which in turn can influence architectural or environmental properties.

Performative materials are an interesting consideration in the design of new architecture. If it is possible to quantify the characteristics of the materials and then encode their relationships with context and geometry, then the material qualities themselves can become drivers of parametric design.

4. New paradigms

The original source of all materials is nature. As we continue to develop new synthetic materials it is important to retain an understanding of the natural relationship between geometry and material, as often the millennia of evolution can inform us about logic and equilibrium in design.

Biological processes are inherently concerned with conservation of energy, and typically geometric adaptation is less energy intensive than the creation of new material. In most natural processes, geometry is a variable and conservation of material is the rule.

Figure 1. Windswept tree: biological reaction of growth and geometry to applied forces.

By contrast, structures designed for constructions are typically static applications of homogenous materials. Compared with their natural counterparts, synthetic material strategies appear to be less efficient; load bearing is typically achieved by adding material or changing material rather than by adapting geometry for conservation of energy.

5. New geometry

The laboratory for architectural production (lapa) has established research collaborations with material scientists, engineers, and industry. These collaborations focus on finding new and efficient architectural applications for materials, and specifically materials which have performative characteristics. The long term research goal is to develop methods in which geometry is "informed" with either material characteristics or the potentials and constraints of the fabrication processes. This approach to inform geometry is aimed at improving the sustainability, efficiency, and technical innovation in design.

5.1 ORIGAMI PAVILION

Our first project collaboration sought to develop a structure using the façade material "Alucobond" made by Alcan Composites. Alucobond is an aluminium composite panel (ACP) "sandwich" material composed of thin sheets of aluminium alloy bonded to a core of polyethylene plastic. Through the composite characteristics, the material has a very strong rigidity compared with its weigh to thickness ratio. The material Alucobond is not in itself new, so to retain exclusivity of the product offerings continual innovation is required to create "patentable" products. As such, the manufacturer was interested in engaging with our research lab to develop new ideas for innovation within the ACP market.To begin our collaboration, the composite material was extensively tested in our digital fabrication lab to determine structural and fabricative limits as related to our digital processing capabilities. The primary focus of this stage was to learn how to work the material, while at the same time to see how the material reacted to the forces and processes of CNC controlled tools.

5.1.1 Performative enhancements

Alcan Composites has developed a range of new "performative" coating technologies, each with chemical, structural or fabricative properties which react to external influences. Our group was presented with a list of potential performance qualities, and asked develop a project with one of them.

Our eventual choice was to experiment with the photo catalytic "anti-pollution" surface. This coating uses nanotech polymers imbedded with Titanium Oxide to coat the Alucobond. When exposed to sunlight, the coating strips Nitrous Oxide (a significant polluter and green-house gas) out of the surrounding air and catalyzes it into harmless nitrates which are then either washed away by rain or blown off by wind[i]. This same catalytic process has been used in other materials (concrete, paint, and plastics) but as it is dependent on surface area exposed to sunlight, it is particularly good for application of facades and roofing material.

The performative characteristics of this "new" material change the traditional design approach to efficiency. Typically the process of design optimization is to try to minimize the amount of material in any construct (less material = cheaper). With this performative material, however, this equation is inverted. The "environmental friendliness" of the material is directly proportional to its exposed surface area, so this means that the typical approach to material usage is inverted (more material area = better performance).

5.1.2. Parametric geometry

To make the performance concept functional requires large areas of Alucobond, however at the same time there is still an environmental cost in the high embodied energy of aluminium. To offset this, the design was still optimized and any non-performative material in a structure was minimized. As such the design became a parametric and geometric problem: How to get the single Alucobond material to play multiple roles in the most efficient way?

Collaboration with Dr. Hani Buri from the iBois laboratory at the EPFL; – whose doctorate research investigated the efficiency of folded structures – brought the primary structural concept of "origami like" counter folding to the project. Through geometric folding of the ACM material we were able to eliminate all support structure, create large surface area spans of over 8m with a material thickness of 4mm.

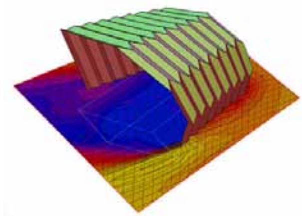

Figure2. Wind and solar analysis

The geometry of the folded shell structure also had to incorporate the need to maximize the solar exposure, so as to maximum the area photo-catalysing pollution at any one time. For best solar potential the folds needed to be balanced between being tall enough to provide structural benefit, but flat enough to minimize "self- shading" at lower sun angles.

From these design concepts, a generalized set of performance biased parametric relationships could be derived. The remaining data required to complete the contextually specific (and therefore not abstract) design was the inclusion of accurate local solar and weather data. This statistical information was used to maximize solar potential based on site specific data of solar orientation, weather, and wind. This data was compiled using Ecotect, and the script integrated spread-sheet data points to refine the folded structural geometry. The resultant script produces a folded parametric "origami" structure that can be designed for size (within material constraints) and whose geometry is responsive to site parameters and orientation.

5.1.3. Proof of concept

As a "proof of concept", the research team and eight students constructed a small pavilion using the material with the machines in our CNC production workshop. For expediency, the resulting design for the built structure was simplified from the angular parametric geometries. In the development of the design and construction there was a significant emphasis paid to maximizing the size of the fabricated components, minimizing the number of components, standardizing the connections, and ensuring the quality of the final joints. This was all done as a strategy for optimization of fabrication, assembly, and on-site construction time. The final pavilion was designed, prototyped, fabricated, and assembled by our students - from the paper folding to the opening party, in eight days.

Figure 3. "Performative" Alucobond pavilion

6. New scales of fabrication

The final project to be discussed is a current collaboration work, and is on-going, so it is not being present as a finished product, but it is rather being presented for its value in demonstrating the potential of small scale materiality and its influence at the macroscopic and structural levels of design.

6.1 ALUMINUM FOAM

Through our collaboration with materials and fabrication researchers, our team was presented with new processes of making foam metal "cores" for heat exchangers. Open cell metal foam has very efficient qualities for heat exchangers, but they have very unique appearances and sets of characteristics. The Alcan Innovation Cell[ii] had developed a new process for faster, more efficient, and less expensive production of aluminium foam. To offset the costs of process development, the material scientists were looking for other potential applications for the material, and as such approached our group to see if it would be of interest to designers or architects.

6.1.1 Open cell foams

The new (patented) process involves making a "moulding wafer" using a proprietary pellet material, and then using high pressure injection casting of aluminium to make a solid block. The block is then opened the wafer material is dissolved, leaving behind an open cell aluminium foam.

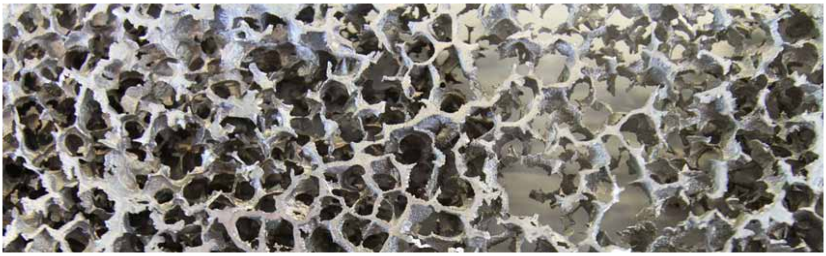

Figure 4. Detail of the parametrically variable open cell aluminium foam.

In closer analysis of the material, it was apparent that the material's structural properties are directly related to the density and patterning of voids caused by the moulding pellets. If this patterning could be organized and structured then the structural properties of the foam could be manipulated.

6.1.2. Performative enhancements

One of the "holy grails" of material design has long been to develop a material that responds precisely to the forces that are implied on it, as happens in nature, where adaptation of geometry is the prevailing method to accommodate forces. This can be seen in the growth pattern of trees (Figure 1), in the directional growth of bamboo, and also in the growth of bone (Figure 5). Localized bone density is directly related to the resistance of applied loads. This can be seen in the cross section of a human hip bone, (Figure 5) but is more radically apparent when looking at the lightweight and efficient bones of birds (Figure 6), where loading points are visibly reinforced.

Figure 5. Cross-section detail of a human hip bone.

Because of the similarity of geometry between the aluminium foam and bone, we are now conducting a research project to develop processes of creating the casting wafers such that the resulting aluminium foam can be designed to have *parametrically* defined density.

Figure 6. Cross-section a bird wing bone

6.1.3. Parametric geometry

To accomplish this the material researchers are developing their pellet casting material to have heat modulated properties, so that when cast some of the pellets shrink making smaller voids, and some of them grow making larger ones, and some of the pellets will evaporate completely leaving space for solid metal. This provides the basis for the foam organization. To physically lay and order the pellets a prototype machine being adapted 3D printing technology is being developed. The machine will "print" the variety of pellets in a programmed order, so as to "pre-set" the mould for casting. The layout, density, and mould-wafer characteristics will be determined using a combination of Finite Element Analysis software to determine the material strength locations, CAD programming to develop the pellet layout algorithms, and meshing and 3D printing software to create the NC code for the pellet deposition control.

6.1.4. Proof of concept

The current state of the project is at this early prototype stage. The research will now proceed on two levels: improving the system to control the density of material, and then developing architectural application ideas. The goal being to determine if it is possible to create efficient castings of customized structural pieces derived from digital analysis. Variable density casting holds strong potential to create customized engineered pieces with tailored structural qualities. Thus far, as the process is still in development, costing factors are not known, but it is estimated that costs will be competitive with a fully machined solid block, with advantages in minimized material waste, embodied energy, and material stresses[vi]. This process is considered a development step in a larger investigation to produce force adaptive and dynamically performative materials. The opportunity for architects to work alongside material scientists and industry has significant promise to bring these innovations to both design and production.

7. Conclusions

The projects described in this paper are a product of design and its interaction with material scientists and engineers, but the concepts, forms, and resulting architecture has been elaborated through the use of parametric digital design software. Architects and designers continue to build their skills and talents in the realm of algorithmic and parametric design scripts, however it is important to understand that the output of these scripts need not only apply to conceptual buildings and abstract forms, but can be used to specifically relate more "abstract" contextual or performative data to geometry. As part of the definition of sustainability, the emphasis on *quality of life*, remains problematic for digital designers due to its highly subjective and non-quantitative measure. However by using the qualitative properties of new performative materials to drive a parametric design we are one step closer to engaging computational design with issues of comfort, environmental impact, and sustainability.

Endnotes

1. The conversion rate of gas to solid means that a significant amount of NiO2 can be extracted from the air, creating a limited amount of NO3.
2. The Alcan Innovation Cell is an on campus research office for collaboration with laboratories at the EPFL

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References

Dyson, A.: 2002. Recombinant Assemblies in Sharples, Holden, Pasquarelli. (Eds.) *Versioning: Evolutionary techniques in Architecture, AD,* Wiley-Academy Press, London, UK; 60–66.

Fischer, C.: 2007, Adaptive composite structures for tailored human-materials interaction. PhD. Thesis, Swiss Federal Institute of Technology – EPFL, Lausanne Switzerland

Jeronimidis, G.: 2004, Biodynamics, in M. Hensel, A. Menges and M. Weinstock (eds.), *Emergence: Morphogenetic Design Strategies, AD,* Wiley, London, 90–95.

Kolarevic, B. and Klinger, K.: 2008. *Manufacturing Material Effects: Rethinking Design and Making in Architecture*. Routledge Press, London, UK.

Mattheck, C.: 2005, *Biomechanics and Structural Optimization*, Karlsruhe: Forschungszentrum Karlsruhe Institute for Material Research. Available from: <www.fzk.de/fzk/idcplg?IdcService=FZK&node=0849&lang=en> (accessed 17/9/2009)

Oxman, N. 2010, Structuring Materiality: Design Fabrication of Heterogeneous Materials in Oxman, R. and Oxman R. (Eds.) *The New Structuralism: Design, Engineering and Architectural Technologies, AD,* Wiley-Academy Press, London, UK; 78–85.

Sliwka, R. 2004, Untimely Fabrications, in S. Williamson (ed.), *Fabrication, ACADIA 2004* University of Waterloo, Cambridge, CA, 52–64.

Vincent, J.: 2001, Smart by Nature, in . Beukers A. and E. van Hinte (eds.), *Lightness: the Inevitable renaissance of minimum energy structures*: 010 Publishers, Rotterdam.