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Specks and Blobs:
Theoretical Developments in Material and Form

Jori Erdman, RA
Clemson University

"...the decision to create the boundless varieties of 'form in itself' through progressive combination of the most manifold bodies, increasingly rich in the parts of which they are composed, was not taken up. Up to the present, building has consisted in the breaking down of forms."

—Hermann Finsterlin, "Casa Nova," 1924

Kenneth Frampton in his text, *Studies in Tectonic Culture* outlines the distinctions between construction techniques and materials as stereotomic and tectonic. The stereotomic concerns primarily homogeneous, load-bearing systems, such as masonry, while the tectonic concerns framing systems with non-load bearing infill. In the twentieth century, we have become proficient in the "tectonic" articulation of architectural enclosures comprised of a system of unique parts made of discrete materials called assemblies. Construction research in the twentieth century, lead by the Industrial Revolution, has been focused on assemblies, frames and curtain walls. However, new research in materials, particularly gradient materials, offer the potential for enclosures which become fully synthesized, with "one" material acting as structure, glazing and mechanical systems, no longer comprised of parts, but rather one unit. This possibility has been pre-envisioned by architects at the end of the century through computer-aided representation.

Since the Industrial Revolution, architectural enclosures have become increasingly thin, light, but also more complex, and technically advanced. Walter Gropius speculated in *New Architecture and The Bauhaus* (1928) that the nature of enclosure would inevitably change based on the emergence of new building technologies, particularly glass. He expressed in this text the Modern desire for an architecture that would allow a more fluid visual relationship between interior and exterior spaces. This proved to be a prophetic observation as enclosure systems evolved throughout the last century.

The post-industrial revolution development of the curtain wall has been one the major architectural feats and an area of research for architectural materials. The curtain wall allowed our buildings to soar higher and become thinner and lighter than ever. The necessity of glass enclosures to withstand tremendous wind, solar and thermodynamic pressures created an entire science of gaskets, sealants, and neoprene washers. The technological complexity contained in a 3-inch perimeter of any large building is staggering and awe-inspiring. The art and science of curtain wall design has become a field of its own and fulfills Gropius' prediction with awe-inspiring dimension.

While buildings have certainly become more complex in the last 100 years, real innovations that transform our way of building have not. Even structures such as the Science Museum at the Parc de la Villette are not major steps forward. The Science Museum engages one of the first major uses of a tensile glazing system, yet the primary tectonic expression of the structural frame is still obvious and necessary. The recently completed Lerner Student Center at Columbia University uses another unique and distinctive system for its combination of ramp and wall, but it does not really propel the discourse of material applications as far as the discourse regarding program. So while our ability to refine the curtain wall has reached great and unforeseen ends, we fundamentally still build in the tectonic.

Here enters the engineer. We have a common problem – the inevitable difficulty in joining dissimilar materials with differing characteristics of structure, thermodynamics, etc. Engineering, which holds to principles of optimization in form and materials, has looked at this problem throughout the aerospace and automotive industry. These concerns parallel the concerns of enclosure for architects. However, optimization theory indicates that more functions performed by the least amount of material with the greatest optimal form will provide the most efficient and "best" solution. Architectural practice focuses on multi-component assemblies rather than looking for optimized solutions. So perhaps we as architects may look to engineers for inspiration and opportunity.

Research into functionally gradient (or graded) materials (FGM's) began in the 1980's with Japanese scientists for the aerospace industry. In 1987 Japanese scientists conceptualized an FGM as an "inhomogenous composite, in which the material's mechanical, physical, and chemical properties change continuously, and which have no discontinuities with the material."[1] In other words, the composition of an FGM changes gradually and systematically at a molecular or atomic level across the form. The transition from one material to another can extend over a large area of the form, or, in the case of coatings, can happen at a surface or small interfacial joint. Three typical applications of FGM's are bulk materials, coatings, and interfacial layers. The principle characteristic of FGM's is that they possess multiple superior material properties simultaneously.

While FGM's have only been conceived of in the late 20[th] century, they follow other previous models. For instance, living organisms have long been known to possess microstructural gradients. One instance, bamboo consists of high-strength fibers within the normal cell pattern. This is a response to the specific flexural loads on certain sections of the plant. Another example of a pre-existing FGM is case-hardened steel which renders a hard surface with a tough interior. Research and development in FGM's has been primarily concentrated in the aerospace industry where materials are simultaneously subjected to high heats and high stresses, however, recent studies have looked at the application of FGM's in the bio-medical field.[2]

Universities around the world including the University of Maryland, Clemson University, and the Massachusetts Institute of Technology Laboratory currently undertake research into FGM's and their production. While several schools are conducting research into the applications of FGM's, MIT really leads the field in terms of FGM production and research. Researchers from MIT presented a paper describing the algorithms necessary for production of FGM's at the 2000 ASME Design of Automation Conference. The paper, entitled "Algorithms for Design and Interrogation of Functionally Gradient Material Objects," outlines the process of Solid Freeform Fabrication through which objects are created from CAD models. The researchers, in conjunction with other groups from MIT developing 3D Printing, are developing computer programs to aid not only in the design and production of objects, but also in analysis. 3D Printing, another MIT initiative licensed to Soligen, Inc, has been used to generate the most cost effective and flexible manufacturing process. Again, little of this research is used in commercial applications as yet.

The most typical materials combined in FGM's are metal and ceramics. In the aerospace industry, this application solves the difficult connection in component parts where parts are subject to extreme heat and strength stresses. Experiments have been conducted where a component comprised of steel at one point smoothly becomes ceramic at another point. The FGM eliminates the previously fragile and failure-prone juncture of the two materials. While this application remains at the experimental level, tests indicate that this component is actually stronger than any previous attempts to combine the materials through accepted methods of assembly and connection. Additionally, glass/metal composites have also been explored, particularly in the field of fiber-optics and biomedical engineering of bone implants.

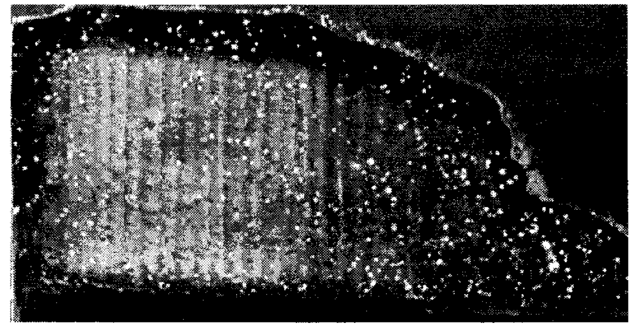

Fig. 1 Example of FGM showing transformation from ceramic to metal.

Much experimentation exists in the fabrication of FGM's using Rapid-prototyping technology such as the 3D Printing at MIT. As an example of the manufacturing process, the 3D Printing process allows for the localization of materials through the layering of materials using binders and rollers to create components. Using inkjet technology and computerization, materials can be strategically and specifically located. Researchers have created FGM's using solids, liquids, and gases in both physical and chemical processes. Methods have included: slip-casting, self-propagating high-temperature synthesis, plasma spraying, vapor deposition, chemical vapor deposition, physical vapor deposition and electroforming. It is in the fabrication of FGM's that the greatest obstacle to architectural applications occurs. All of the current processes are highly sophisticated, yet small scale. This is understandable given the nature of current possible applications. Perhaps the most viable fabrication method for architectural applications is the slip-casting method, which relies on the sedimentation velocity of particles. For engineers in the aerospace industry this technique is too uncontrollable and imprecise, however, it may be more than adequate for the scale and tolerances necessary for architectural applications.

One interesting byproduct of the fabrication of an FGM is that the process seems to render the materials stronger than non-gradient materials. The potential benefits of FGM's to architectural production are superior efficiency in material use and the elimination of inherent weaknesses in hard surface joints. A building executed in materials that flows seamlessly into one another would greatly reduce failures structurally and mechanically, such as where transparent materials meet opaque materials, or where buildings are subjected to greater thermal stresses. While it is possible to imagine the future of FGM's at a large (architectural) scale, current manufacturing processes severely limit the applicability of the technology.

Fig. 2 Computer model of Cincinnati Day School by Greg Lynn.

However limited the applicability of FGM's, since the early 1990's architects have been working with similar issues of form loosely termed as "blobs." New developments in computer representation have accelerated these formal musings and allowed for certain advancements in fabrication techniques. However, these proposals have yet to live up to the latent potential within them for developments in construction and materials. New advances in engineering known as functionally gradient materials may provide a material expression these formal investigations portend. At this point, the blob-forms proposed by architects are still crudely executed in the frame/sheathing assemblies we have become familiar with in the twentieth century.

For example, Greg Lynn investigates organic form in his work. He uses computer-processing capabilities to generate the forms he calls "blobs." Leaving aside the philosophical and mathematic genesis, the blob proposes a continuous form where the wall becomes the roof and creates fluid spatial relationships. His project for the Cincinnati Day School explores this strategy for architectural structure.

The project's formal characteristics are typical of the "blob" method and form. However, most of these investigations remain at the level of architectural theory and propositions. Lynn attempts to execute the blob in the physical realm in his project for the Korean Presbyterian Church.

The Korean Presbyterian Church project, completed in 1997, is Lynn's first attempt to translate the blob into real materials. The project is constructed using typical stick frame construction, tectonics. The resultant forms are awkward and belie the sophisticated formal models as constructed on the computer. Most evident on the exterior of the building, the project reveals the ultimate failure of contemporary materials to live up to the promise indicated in the representations of form.

The interior spaces more successfully articulate the model, but this is mostly possible because of the more flexible nature of interior materials and methods of construction. However, the radical proposals Lynn makes in his practice may be more possible with the eventual employment of FGM's.

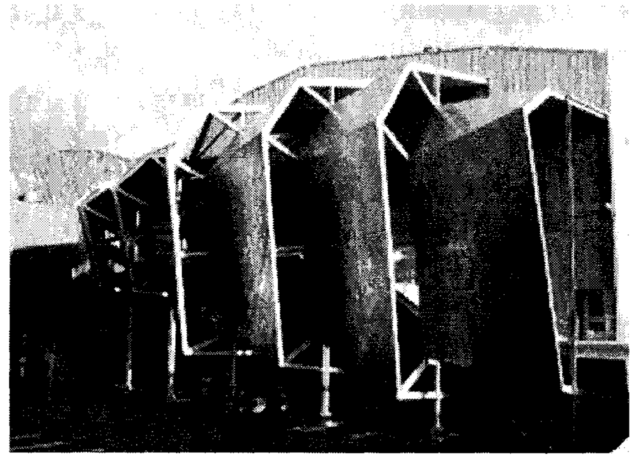

Fig. 3 Exterior of Korean Presbyterian Church by Greg Lynn.

Fig. 4 Water Expo by Nox Architects.

Another example of this type of formal investigation is evidenced in the work of Nox Architects. Their project for the Water Expo — Aquatic Pavilion attempts to capture the fluid nature of water. The expression of water becomes rendered stiff and rigid when constructed with sticks of wood and steel and planes of plywood.

Although these materials bend and be shaped to take on other forms, their inherent nature is straight and linear. While it could be argued that the materials transcend their nature in this project, what would it become if executed in FGM's, where one material seamlessly becomes the next, smoothly transitioning between structure and skin, opacity and transparency?

Philosophies of organic systems point to the inevitability of such structures as part of the natural evolution of form. Functionally gradient materials offer the possibility of new architectural expression, evolved out of developments in the 20th century but distinctly different from historical models. How these materials transcend the obvious and ordinary into the poetic is the question that architects must answer. This paper proposes new engineering advances in functionally gradient materials as a possibility for material development with architectural applications. In addition, this type of material indicates a total reconceptualization of materials and their properties, moving from a process of assembly to the entire form.

NOTES

[1]T. Hirai, M. Sasaki, and M. Niimo, quoted by A. Neubrand, "Functionally Graded Materials," *Encyclopedia of Materials: Science and Technology* (2001): 3407-3413.

[2]K.L. Choy, "Functionally Graded Materials," *'The Encyclopedia of Advanced Materials* (1994): 905.

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