FAB Finding

Towards a Methodology of Material Guided Digital Fabrication

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The distinction between material behavior (mechanics) and material response (electronics) in the framework of responsive building skins has promoted unique design protocols for integrating sensor technologies into material components. Such a distinction results in the implementation of remote sensing devices post the process of material fabrication. Sensors are commonly perceived as electronic add-on patches which initiate mechanical output with response to electrical input. This work seeks to establish a novel approach to the integration of electronics in building skins which prioritizes material selection, behavior and fabrication given a required task, over post-production sensor application. The term "FAB Finding" is proposed to describe an instrumental methodology facilitating the coupling of CNC fabrication processes with material organization and behavior. It offers a design mentality which emphasizes the nature and the effects brought about by the use of specific fabrication processes which are by definition inherent in the design product and its behavior. A light-sensing inflatable skin system is developed as a working prototype demonstrating such an approach.

Keywords: *Digital fabrication; material behavior; form-finding; sensors; responsive skin.*

Introduction

Background

The material and technique in which a natural artifact has been formed is directly linked to its behavior (McQuaid, 2005). So ways of making things are inextricably associated with what and how they serve as final artifacts. Today, rapid prototyping (RP) and computer numerically controlled (CNC) fabrication technologies offer an abundance of choices for making things, to the point where any given choice of material substrate and its respective fabrication technique or technology will inform the way in which the design product manifests itself by means of efficiencies and effects (Sheil, 2005). It is precisely this state of abundance which promotes and/or requires the designer to carefully match an agent to an agency (or the other way around). Techné, the Greek word for "craft" suggests that such decisions are not innocent in the larger scope of design generation, and that there is more to design materialization then simply hitting the power switch. Recent initiatives capitalize upon intelligent construction methods based on the correspondence between digitally driven form-finding processes and digitally driven material processes (Cabrinha, 2005 and Oxman, 2007). However, most of the work done in this area is focused on the relation between relatively complex geometries and fabrication in static structures (Kilian, 2003 and Bechtold 2000, 2004). Such research demonstrates the need for an integrated approach to materials and fabrication techniques which goes far beyond efficiencies of construction (Sass, 2007).

Through the design and fabrication of a light sensing inflatable skin prototype, this paper suggests that machine execution through digital fabrication should not merely be regarded as a service tool for materializing design but rather an opportunity to inform the design process by integrating machine-logic with material behavior. The task of designing a responsive skin system may be considered as an extreme case of handling input and output data and their integration with material form (geometry) and behavior (performance). In the process of designing a sensate-responsive skin, this work integrates a wide range of skills and applications, from wood milling to electronic programming of sensor-integrated circuits, with the aim of promoting a holistic approach to "FAB Finding".

Problem definition

An intelligent wall or a responsive skin is, at its simplest, an environmental manifestation of technology that is already being appropriated (Bullivant, 2006). However, in much of the work generated recently which falls under the umbrella of "responsive environments", there still exists a separation, both in process and authorship, between "what" a building senses, and "how" it does so.

Firstly, the use of a specific material-processing technique along with its limitations and constraints (however inspiring) directly informs the design product across scales of function and performance (Schodek, 2005). Secondly, electronics is mostly embedded in the artifact post its production and assembly rather than considering an appropriation between the sensors and the sensing elements of the building.

In most of the work shown here, "digital presence" (or any proof of CAD) is absent in most cases: complex geometrical form is fabricated through physical matter, and sensors are embedded within it as potentially seamless and ubiquitous elements enhancing material response to local stimuli. One of the crucial ideas that this work seeks to portray is that of "integrated electronics". Simply put this means that instead of simply "adding-on" sensors to the artifact, material choice and processing is targeted towards, and guided by, an understanding of the mechanical properties which initiate dynamic behavior.

Aims and objectives

The aim was to construct a working prototype for a sensate building-skin which modulates its surface with response to light. All mechanical and electrical elements of the prototype were designed as integrated parts, each of which was programmed and/or fabricated to suit its structural performance, and potentially control its environmental performance. Such a building skin, the behavior of which is directly informed by its environment, may promote the notion of efficiency (environmental, programmatic etc) through the local control of its components.

Organization

The fabrication process of this exploration included a range of tasks and tool-customization processes which may promote a new sensibility to the integration of material, behavior and machining modes that has been designated by the author as "FAB finding". Such processes include the devising of add-on tools and the usage of multiple machining modes such as cutting, etching and scoring. Following the introductory statement which seeks to establish some theoretical foundations for "FAB finding", the paper demonstrates the processes and tools used to design and fabricate the prototype. The second chapter demonstrates tool customization and electronic

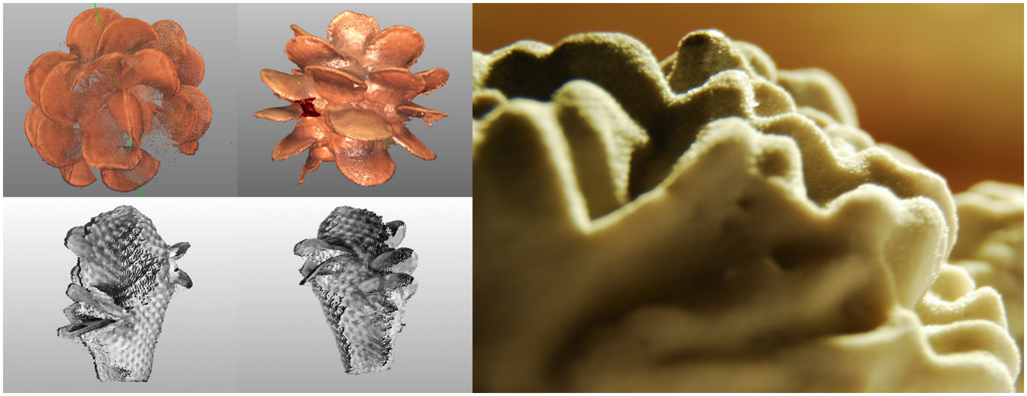


Figure 1
3-D scanned cones. Two types of cones were 3-D scanned in order to create a 3-D reconstruction of the natural artefacts. These reconstructions were then examined aiming at understanding the relation between performance and geometrical attributes.

integration processes by presenting the design aim and the corresponding tools / CNC machines used for that purpose. The final chapter demonstrates the prototype, followed by summary and conclusions.

Process demonstration: CNC/RP tool customization and electronic integration

CNC/RP design generation

Environmental Cartographies: Analysis of Natural Artifacts [3D Scanning and Printing] as Case Study: The exploration commenced as an attempt to understand how certain natural structures operate within their environment. In search for a "breathing skin" model, a surface structure which would allow for global and local modulation of its parts with response to environmental stimuli - natural pine cones, which use light energy to induce motion, were scanned and modeled. The following images below (figure 1) illustrate the point-cloud generated after registration.

Inherent Tectonics: Surface Dynamic Behavior [Laser Cutting (LC)]: The notion of an inherent tectonics implies that certain characteristics of the system at hand which describe its construction may be brought into consideration in the fabrication process itself. So once fabricated, the system presents a range of behaviors which have been accounted for in the fabrication and assembly process. This notion is particularly relevant when designing adaptive systems which introduce a high degree of

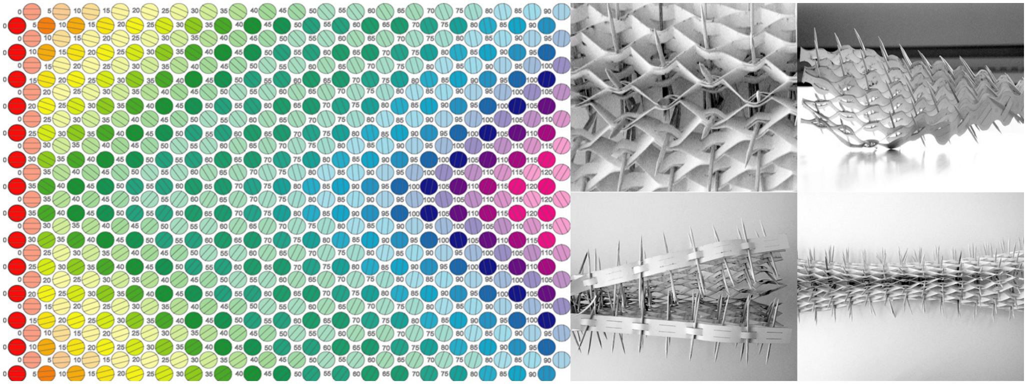


Figure 2
Differentiated distribution of assembly slots: In this experiment, the slots which were used to assemble the strips were placed at different angles, such that for every slot on a given strip - the angle increases gradually. Such layout resulted in a flexible doubly-curved surface. The image to the left shows the slot-angle layout as a continuous map of the registered angles, colour coded from 0 deg to 90 degrees.

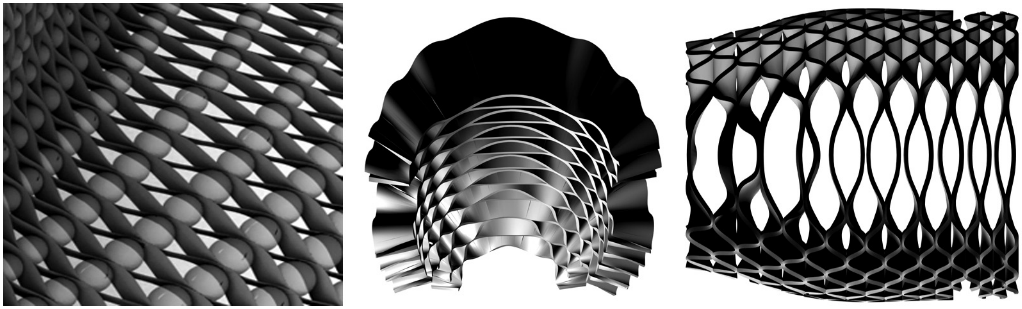


Figure 3
Digital modelling of surface behavior: The model was generated using a parametric software package, where small sphere-like elements increase and decrease volume parametrically, to allow for the simulated "stretch" effect of the surface.

complexity into the design. Establishing the range, increments, and limits of adaptability may be accounted for by coupling the fabrication technique with material behavior and its geometrical characteristics. The following experiments demonstrate this notion by introducing a specific logic of cuts into the paper and stainless steel models (figures 2, 3), the geometry of which allows for a unique local and global structural behavior to emerge. For example, the following images demonstrate how a 180 degree rotation of cut lines which connect adjacent strips, allows for the generation of curvature in the surface, once stretched.

Parasite Tooling by Add-On(s): Generation of Cylindrical Structure [LC Rotary Station]: The cylindrical structure was designed to support scale-like elements and allow sufficient room for the inflatable bladder to be installed inside it. In order to cut the structure (fabricated from acrylic), a mandrel structure has been constructed to support the acrylic tube to be cut (figure 4, right image).

The diamond-like engravings of the surface indicate the laser registration of the tool-path as it rotates the tube in constant motion. The Rotary Station is an add-on tool which may be placed on the laser-cutter bed to allow for rotary-cutting. The gear-driven CNC Rotary Axis permits cutting profiles or tubes in different diameters. Instead of an X and a Y axis, the laser beam is calibrated to the circumference of the tube as its Y axis. The Rotary Station is plugged into the LC bed with a serial connection, allowing all geometrical information to be converted from planar to tubular format. The cutting pattern should be unfolded in digital form to allow for the cutting process to occur.

Multiple Craft (Machining) Modes: Construction of Flexure Structure [Water-Jet Cut/Etch (WJC/E)]: The ability to process material in a multitude of

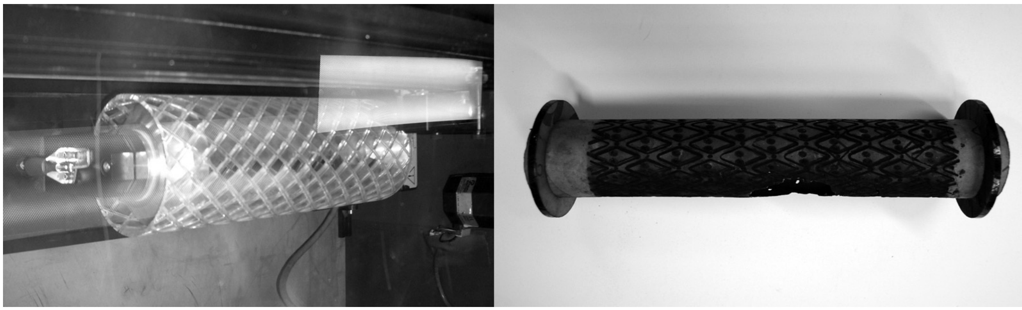
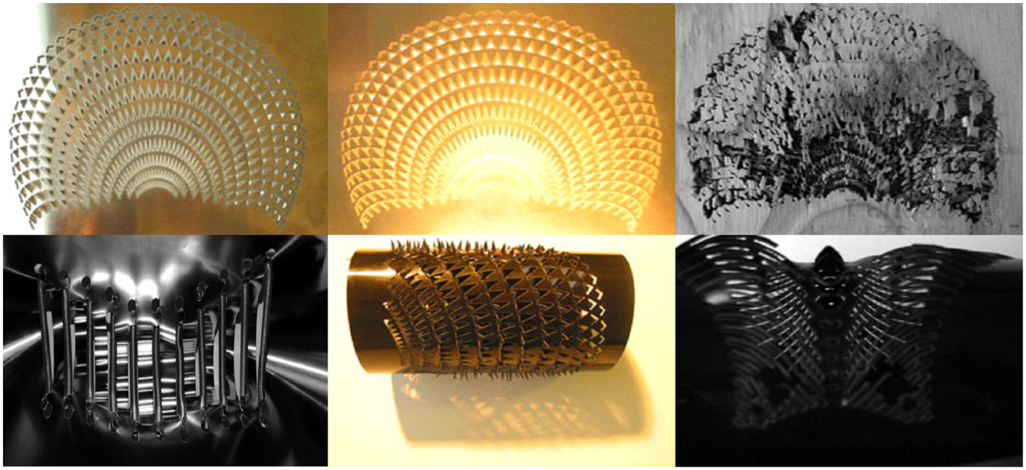


Figure 4
Scale support structure. Images illustrate the final acrylic piece that was laser cut using a laser rotary station and the mandrel generated to allow for the controlled cylindrical cutting.

Figure 5
Parallel and nested etching patters in flexure structures (stainless steel and shim stock using the WJC)



machining modes (such as cutting, scoring, etching etc.) allows one to achieve certain material behaviors when the material is being stretched, folded etc. In this case, using the water jet cutter, stainless steel sheets were cut and etched to allow for a scale-structure which behaves like a flexure. Flexure structures are structures which present a large range of motion when load is applied (Bending deformation, i.e., deformation by increasing curvature), and have minimal (or no) joints. In that sense, a flexure behaves much like a fabric, or a continuous mesh, allowing for local loads to propagate across its entire surface. Such structures were explored for the flexible scale surface, which would deform with response to light. The initial exploration demonstrates the ability to achieve a three-dimensional structure from a two-dimensional pattern. The cut components are all identical in topology but differentiate according to their relative location in the pattern, thus, initiating curvature upon folding the sheet material itself. In addition, the sheet behaves as a flexure initially by flipping the direction of the cuts from side to side upon folding internally or externally (figure 5). Potentially one could imagine a force-flow through those cuts which determines their orientation locally, as componentized flexure elements. This exploration seeks to devise the nesting of cuts (etched, no cut-outs) as a method for generating flexures. The material used here is shim stock (a type of plastic) – thin as a sheet of paper but isotropic.

Inherent Tectonics 2: Air Bladder Construction [Moulding / Vacuum Forming]: The aim was to generate an interstitial skin which would consist of a semi-structural mesh and a system of inflatable bladders (figure 6). From bottom to top the different layers consist of the following materials to form a composite fabric: (1) 3D printed mould modeled in 3D and printed in the Z-Corp. (2) Flexible wires inserted in plastic tubing to form the structural elements. (3) Polyurethane mould. The process of applying the liquid plastics repeated twice so as to allow for a double layer to be produced. Once inflated with air, the structure was to inflate, held by the wires in the seam lines positioned in the mould.

Electronic integration

Material Stimulus (Sensor Input): Light Sensor Circuit Design [Microcontroller Programming]: The prototype was designed to convert light energy into mechanical motion. A circuit board which reads visible light levels as input data and converts them into voltage was designed (figure 7). Voltage levels are then converted

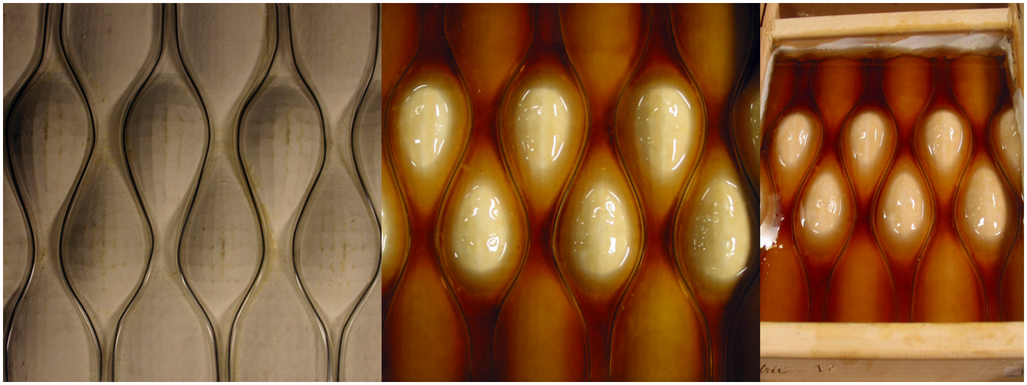


Figure 6
3-D printed mould with wires (inserted in plastic tubing). The composite structure allows for the incorporation of the structural elements (bent wires) within the skin (rubber), which was designed to allow for inflation "pocket" elements.

into mechanical motion (air inflation initiating skin movement) as output. An Infra-Red (IR) Phototransistor was used and a Graphic User Interface (GUI) was programmed to illustrate the step-response cycle, the curvature of which indicates capacitance value per one step (1 2 3 4 framing) over time. An additional interface was developed which converts voltage units to candelas (approximating the 1 to 5 volt range to the IR wavelength). The Processing (JAVA based software) serial library allows for easily reading and writing data to and from external machines. It allows two computers to send and receive data and give back the flexibility to communicate with custom microcontroller devices, using them as the input or output to the JAVA based PROCESSING program.

Material Excitation (response output): Motor Integration [Microcontroller Programming]: Prior to integrating the light sensor with a motor which would allow for air-pumping into the structure, this exploration looks at a much simpler problem: the actuation of a motor and a fan to blow up a sealed plastic bladder connected to it.

Sense-response Integration: Light-Air Conversion Protocol [Microcontroller Programming]: The circuit-board schematics (figure 8 on the right) illustrates the general layout in which the light sensor and motor are integrated. The INPUT header to the right of the image indicated the connection to the light-sensor which will extend ideally for each scale element in the skin. The VALVE at the bottom left indicates the position of the motor, actually a solenoid valve (figure 8 on the left) which simply acts like a gate that targets the air from the pump to the bladder. The gate opens with response to light: beyond a

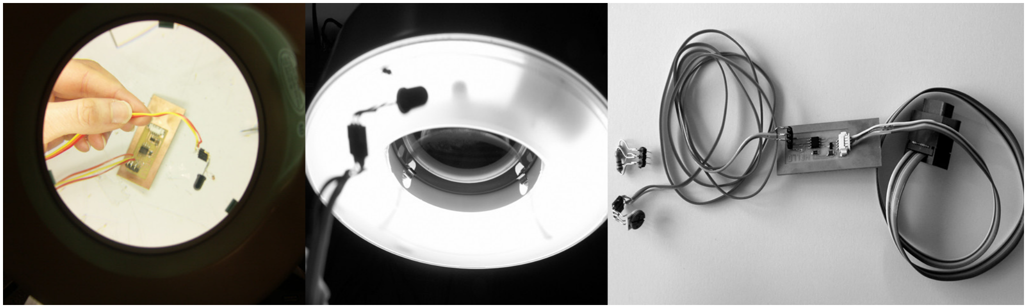


Figure 7
Circuit board and light sensor integration. The circuit was designed to read light levels and convert them into voltage, which in turn would allow for the inflation of bladders within the structure.

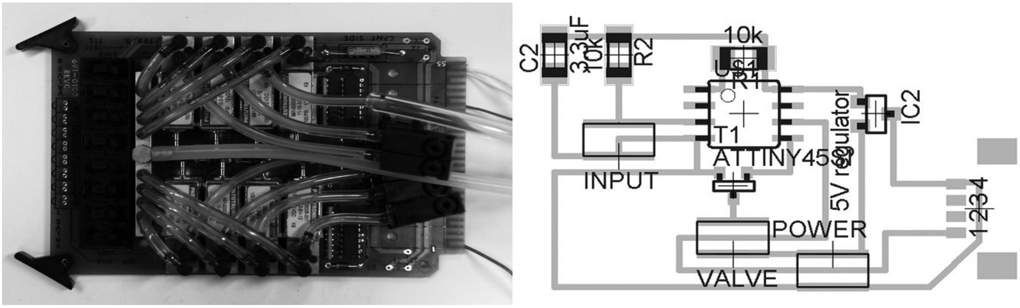


Figure 8
Ligh-Air Conversion Protocol Image showing the solenoid valve board and the circuit board schematics

given light level, the gate opens, and air is pumped to a local bladder attached to a scale component on the skin structure. The circuit board itself is comprised of the INPUT header (light-sensor), the "output" header (valve), the Microcontroller, resistors, a capacitor and a transistor (figure 8 on the right).

Prototype demonstration

The structural skin is made up of a cylindrical diagonal grid support-structure to which are attached the light-sensing scales. The scales are made of stainless steel sheets, custom cut to fit the cylindrical mesh (figures 9, 10).

Each scale is designed to accommodate a light sensor within its surface area, and a structural peg-like element attached to its interior surface which would allow for effective inflation of the local component. Preceding from the cylindrical construction generation the goal was to design an interstitial skin which would act as air-bladders for each scale on the skin.

Figure 9
Digitally generated parametric models showing the scale elements and the nested cutting pattern for the Water Jet Cutter (WJC). The global surface was rationalized to a ruled (cylindrical surface) out of which the scales were cut and assembled.

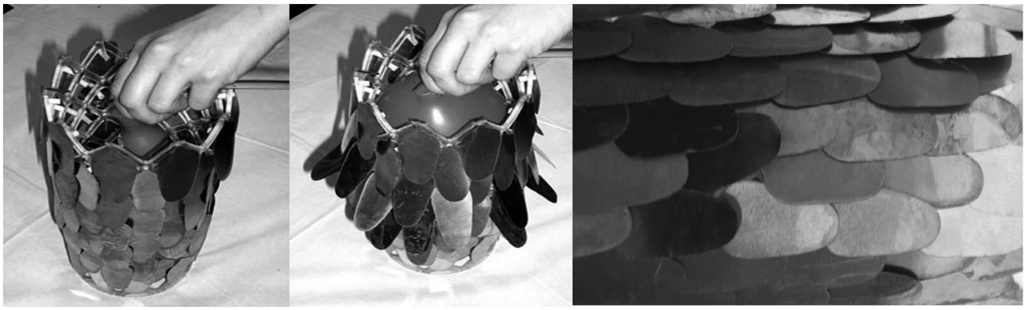


Figure 10
Final prototype (work in progress) showing scale in motion with response to the changing light levels. The images illustrate closed and open states of the final model, incorporating scale geometry and material behaviour as the parameters establishing the final form.

The general aim was to generate an in-between skin which would consist of a semi-structural mesh and a system of inflatable bladders which would inflate locally. The skin is made of stainless steel scales, placed on a cylindrical structure, which tilt with response to light in a localized manner such that the tilt degree is directly informed by light levels. In this prototype an inflatable skin allows for the reconfiguration of its local members.

Summary and conclusions

The term "FAB Finding" which follows from the notion of "form-finding" emphasizes the role of digital fabrication as a design driver in and of itself. It stresses that the coupling of a given tool to its task is instrumental to the design process itself. This work attempts to establish "FAB Finding" protocols for a light-sensing inflatable skin system. By developing a working prototype which incorporates material and electrical behaviors and properties through the use of a range of rapid prototyping and CNC tools, this exploration demonstrates design abilities to integrate physical and digital media as scaled constructions and performance-driven architectures, beyond their traditional role as representation and simulation media. Moreover, beyond the demonstration of a working prototype, the description of "design through fabrication" may support such material sensibility in design. Each exploratory phase aims at establishing a conceptual framework which may promote such novel interpretations of digital design tools, techniques and technologies. Finally, the notion of "FAB Finding" is manifested in this work as a design method which promotes the creation of novel structural systems through processes of digital fabrication and assembly. Sensors, and other applied electronics, become ubiquitous in that they are considered part of the material system at hand, and at the same time, define its behavior.

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