mentals, we can reduce energy use by a factor of ten by discretely acting only where necessary, then all will benefit. If we can move away from the overarching idea of a fully interconnected, and thus controlled, infrastructure, and operate discretely and locally, then many of the advantages offered by new technologies can be appropriated by a greater diversity of projects.

The potential, however, for rethinking our normative deployment of materials extends far beyond the notions of efficiency and expediency. In Chapter 1, we suggested that the advent of smart materials would eventually enable the design of direct and discrete environments for the body. What does this mean in the context of the chapters that followed? Fundamentally, it means that design begins with a single, small action. Rather than designing the static shell of the building, and then progressively moving smaller, with each step in the process geared toward greater delineation of the design artifacts, we may have the opportunity to move in the opposite direction. We now have technologies that can do anything, even though they would rarely be visible. The artifact could support the design intent, instead of being its physical manifestation. We come back to the questions of what the experience could be, what the occupants should feel, how they would interact with their surroundings. Instead of designing at a large scale to produce ancillary effects, we might be able to design at the small scale to produce a larger human experience.

When we first began teaching courses in smart materials, we derived an expression for what we considered to be their ultimate goal:

direct and immediate action at the precise location so desired.

We still think so today.

Notes and references

1. Lightman, A., Sarewitz, D. and Dresser, C. (2003) 'Introduction', in *Living with the Genie: Essays on Technology and the Quest for Human Mastery*. Washington, DC: Island Press, pp. 1–2.
2. Ferreira, Paulo J. (2004) 'Nanomaterials', in J. Brito, M. Heiter and R. Rollo (eds), *Engineering in Portugal during the 21st Century*. Lisbon: Don Quixote, p. 3.
3. Lightman *et al.*, *Living with the Genie*, p. 67.

Glossary

Absorptance (acoustic) — the dimensionless ratio of incident vibrational energy that has been converted to another energy form, such as heat, to the total incident energy on a material surface. The working definition of absorptance is slightly different: the dimensionless ratio of incident vibrational energy that is *not reflected* to the total incident energy on the surface. A perfect absorber with a reflectance of 1 reflects no energy – all the incident energy may be absorbed or transmitted.

Absorptance (luminous) — the dimensionless ratio of incident radiant energy (in the visible spectrum) that has been converted to another energy form, such as heat, to the total incident energy on a material surface. A perfect absorber with a reflectance of 1 reflects and transmits no light.

Actuator — a control element that is driven by a signal, often electrical, that produces enough power to operate a mechanical element, such as a valve. Common actuator types are electromechanical, hydraulic and pneumatic.

Aerogel — generically describes any colloidal solution of a gas phase and solid phase. More typically, aerogel refers to a specific material.

Artificial Intelligence — programs that can perform activities that are typically associated with human intelligence, such as recognition.

Augmented reality — a composite view constructed of a real scene overlaid or augmented with a virtual scene.

Biomimetic — the imitation of nature or the study of the structure and function of biological substances.

Birefringence — Occurs when an anisotropic material possesses different refractive indices depending on how the incident light is polarized.

Bioluminescence — light produced by living organisms through an enzymatic chemical reaction.

Biosensor — a general designation that refers to either a sensor to detect a biological substance or a sensor that incorporates the use of biological substances in its construction.

Chemochromics — materials that change their color in response to changes in the chemical composition of their surrounding environment.

Cladding the outer sheathing of a building that provides the final layer of the envelope. The cladding is exposed to weather and thus needs to be durable while, simultaneously, it is the cladding that is most responsible for a building's appearance.

Composite a multi-component material produced when metal, ceramic or plastic materials provide a macrostructural matrix for the distribution of strengthening agents, such as filaments or flakes, throughout the material, increasing its structural performance. Each component, however, maintains its properties.

Conduction (electrical) the transmission of electricity through the movement of electrons.

Conduction (thermal) the diffusive transfer of heat and mass, through direct molecular contact.

Conductive polymers organic materials that conduct electricity.

Convection specific motion in a fluid material that results in heat and mass transfer.

Copolymer a polymer that consists of two or more distinct monomer units that are combined along its molecular chains, in block, graft or random form.

Critical angle the smallest angle of incidence that will produce total internal reflection at an interface boundary between two mediums with different refractive indices.

Curtain wall an exterior non-load bearing skin of a building.

Detector a device that responds to a change in some energy – usually light – and produces a readable signal.

Dichroism a diochroic material that has selective spectral absorption that differentiates its transmissive spectrum from its reflective spectrum.

Dielectric a material that is electrically insulating, i.e. a very weak conductor.

Distributed intelligence the distribution of intelligent entities throughout a system, with no distinct center.

Doping the addition of donor or acceptor impurities into a semiconductor material to increase its conductivity.

Elastomers polymers that have largely amorphous structures, but are lightly cross-linked, and are thus able to undergo large and reversible elastic deformations.

Electrochromics materials that change their color in response to changes in an electric field; often used to change the transparency of glass laminates.

Electroluminescents materials that luminescence or emit light when subjected to an electric field.

Electromagnetic radiation a large family of wave-like energy that is propagated at the speed of light. The electromagnetic spectrum encompasses wavelengths from as small as gamma rays to as large as radio waves.

Electrostriction the change in shape produced when a dielectric material undergoes strain when subjected to an electrical field.

Electrorheological ER fluids contain micron-sized dielectric particles in suspension. When exposed to an electrical field, an ER fluid undergoes reversible changes in its rheological properties including viscosity, plasticity and elasticity.

Emergent intelligence an intelligent system that is bottom up, emerging from simpler systems.

Emissivity the measure of the ability of a surface to emit thermal radiation relative to that which would be emitted by an ideal 'black body' at the same emperature.

Envelope the term describes the three-dimensional extents of a building.

Extrinsic property a material property that depends on the amount or conditions of material present. Whereas density is intrinsic, mass is extrinsic.

Ferroelectricity the alignment of electric dipoles in a material to produce spontaneous polarization when it is subjected to an electric field.

Ferromagnetism the alignment of magnetic dipoles in a material to produce spontaneous polarization when it is subjected to a magnetic field.

Fiber-optics strands, cables or rods that carry light by internal reflection; used in lighting and communications. The fibers can be glass or of PMMA.

Fluorescence fluorescence is the property of some atoms and molecules to absorb light at a particular wavelength (higher energy) and to emit light (luminescence) of longer wavelength. If the luminescence disappears rapidly after the exciting source is removed, then it is termed fluorescence, but if it persists for a second or more, it is termed phosphorescence.

FOLED flexible organic light-emitting devices built on flexible substrates typically used for flat panel displays.

Fresnel lens a type of flat lens with a concentric series of simple lens sections that either focus parallel light rays on a particular focal point or, alternatively, generate parallel rays from a point source.

Gels any semi-solid system in which liquid is held in a network of solid aggregates.

Haptics the production of a tactile sensation, such as heat and pressure, at the interface between a human and a computer.

Health monitoring (structural) the comparison of the current condition to earlier conditions to proactively predict potential failure. Most often used for large structures such as bridges and building foundations.

HVAC an acronym for heating, ventilation and air conditioning.

Hydrogels three-dimensional molecular structures that absorb water and undergo large volumetric expansion.

Illuminance the density of light flux on a surface, the ratio of incident flux to the area of the surface being illuminated.

Incandescence the production of light through heat.

Index of refraction the ratio of the velocity of light in a vacuum to the velocity of light in a particular medium.

Inorganic defined as any compound that is not organic.

Intelligent agent software that can perform tasks without supervision.

Internal reflection the process through which light travels within a high refractive index medium.

Intrinsic property a material property that is independent of the quantity or conditions of the material.

Inverse Square Law applies to all radiant propagation from a point source, including that produced by sound and light. The intensity diminishes with the square of the distance traveled.

Laser an acronym for light amplification by the stimulated emission of radiation. A quantum device for producing coherent (parallel) light.

LCD liquid crystal display. The typical display sandwiches a liquid crystal solution between two polarizing sheets. When electric current is applied to the crystals, they are aligned in such a manner so as to block transmitting light.

LED light-emitting diode. A semiconductor device that releases light during the recombination process.

Light pipe although occasionally used to refer to light guides or fiber-optics, the primary use of the term in buildings is for a hollow macro-scaled device that transports light through reflection and refraction.

Liquid crystals anisotropic molecules that tend to be elongated in shape and that have an orientational order that can be changed with the application of energy.

Luminance the light flux that is reflected from a surface.

Luminescence the emission of light from a substance when electrons return to their original energy levels after excitation. Luminescence is an overarching term referring to any light production that involves the release of photons from electron excitation.

Luminescents materials that emit non-incandescent light as a result of a chemical action or input of external energy.

Magnetorheological MR fluids go from fluid to solid when subjected to a magnetic field due to a change in their rheological properties, including viscosity, plasticity, and elasticity.

Magnetostrictive materials that change dimension when subjected to a magnetic field or that generate a magnetic field when deformed.

Mechatronic a term generically used to describe electronically controlled mechanical devices (mechanical-electronic).

MEMS microelectronic machines; typically small devices based on silicon chip technologies that combine sensing, actuating and computing functions. The term is an acronym for micro-electromechanical system but today almost any micro-scaled device is referred to as a MEMS device.

MesoOptics™ a type of coating or film with holographically generated microstructural diffusers that produce optical control of the transmitting light.

Meso-scale length dimensions on the mm to cm scale. Often referred to as miniature.

Microencapsulation individually encapsulated small particles or substances to enable suspension in another compound.

Micromachine a structure or mechanical device with micro-scale features.

Microprocessor the IC-driven arithmetic logic of a computer.

Micro-scale length dimensions on the micrometer to 0.1 mm scale.

Microstructure the structural features of a material such as its grain boundaries, its amorphous phases, grain size and structure.

MOEMS micro-electro-optical mechanical systems; MEMS with optics.

Nanotechnology the exploitation of the property differences between the scale of single atoms to the scale of bulk behavior. Also, the fabrication of structures with molecular precision.

NEMS nanoscale MEMS at scales of 1000 nm or less.

Nitinol a nickel–titanium alloy used as a shape memory alloy.

OLED organic light-emitting devices made from carbon-based molecules rather than from semiconductors.

Optoelectronics the combination of optical elements, such as lasers, with microelectronic circuits.

Organic a term applied to any chemical compound containing carbon as well as to a few simple carbon-based compounds such as carbon dioxide.

Pervasive computing — when computational and interactive devices are seamlessly integrated into daily life.

Phase change — the transformation from one state (solid, liquid, gas) to another.

Phase transformation — change that occurs within a metal system, most often refers to a change in crystalline structure.

Phosphorescence — luminescence that remains for more than a second after an electron excitation.

Photochromics — materials that change their color in response to an energy exchange with light or ultraviolet radiation.

Photodiode — semiconductor diode that produces voltage (current) in response to a change in light levels.

Photoelectrics — devices based on semiconductor technologies that convert light (radiant) energy into an electrical current.

Photoluminescence — the luminescence released from a material that has been stimulated by UV radiation.

Photoresistors — devices based on semiconductor technologies in which the absorption of photons causes a change in electrical resistance.

Photovoltaic effect — the production of voltage across the junction of a semiconductor due to the absorption of photons.

Piezoceramic — ceramic materials that possess piezoelectric properties.

Piezoelectric effect — the ability of a material to convert mechanical energy (e.g., deformation induced by a force) into electrical energy and vice-versa.

Polarization — occurs when the centers of the positive and negative charges are displaced, thereby producing an electric dipole moment.

Polarized light — electromagnetic radiation, primarily light, in which the wave is confined to one plane.

Privacy film — a type of film that is transparent from particular view angles and opaque from other angles (often called *view directional film*).

Pyroelectric materials — materials in which an input of thermal energy produces an electrical current.

Radiant energy — electromagnetic energy as photons or waves.

Radiation — the emission of radiant energy.

Reflectance — the ratio of reflected to incident radiation.

Reflection — the amount of light leaving a surface. Surfaces are subtractive, so the amount of reflected light must always be less than the arriving or incident light. Furthermore, the angle of incidence is equal to the angle of reflection.

Refraction — the bending of a light wave when it crosses a boundary between two transparent mediums with different refractive indices.

Reverberation — reverberation is the continuance of collected sound reflection in a space. The reverberation time is the amount of time it takes for a sound level to drop by 60 dB after it has been cut off.

Self-assembly — self-assembly (also called Brownian assembly) results from the random motion of molecules and their affinity for each other. It also refers to bottom up molecular construction.

Semiconductor — a nonmetallic material, such as silicon or germanium, whose electrical conductivity is in between that of metals and insulators, but it can be changed by doping.

Sensor — a device that quantifies its energy exchange to provide measurement of an external energy field.

Shape memory effect — the ability of a material to be deformed from one shape to another and then to return to its original shape after a change in its surrounding stimulus environment (e.g., thermal, magnetic). In metals, this phenomenon is enabled by a phase transformation.

Shape memory alloys — metal alloys, e.g., nickel–titanium, that exhibit the shape memory effect.

Shape memory polymers — polymeric materials that exhibit the shape memory effect.

Snell's Law — the relationship between angles of incidence and refraction between two dissimilar mediums.

Spectral absorptivity — wavelength-specific absorption. Reflectivity and transmissivity are often wavelength-specific as well. Most materials have uneven absorption spectra.

Suspended particle display — or SPD, a suspension of randomly oriented particles that can be oriented under application of a current.

Thermochromics — materials that change their color in response to a thermal energy exchange with the surrounding thermal environment.

Thermoelectric effect — the conversion of a thermal differential into a current (Seebeck effect) and vice versa (Peltier effect).

Thermophotovoltaic — a device that converts longwave thermal radiation into electricity.

Thermotropics — materials that change their optical properties due to a thermally produced phase change.

Thin films — a large class that is commonly used to refer to any thin amorphous film of semiconductor layers.

Total internal reflection — a phenomenon that occurs at the interface between two mediums when light at a small angle (below the critical angle) is passing from a slow medium to a fast medium.

Transducer — the conversion of the measured signal into another, more easily accessible or usable form.

View directional film — a type of film that is transparent from particular view angles and opaque from other angles (often called *privacy film*).

Wavelength — the distance traveled in one cycle by an oscillating energy field propagating in a radiant manner. The peak to peak distance between one wavecrest and the next.

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