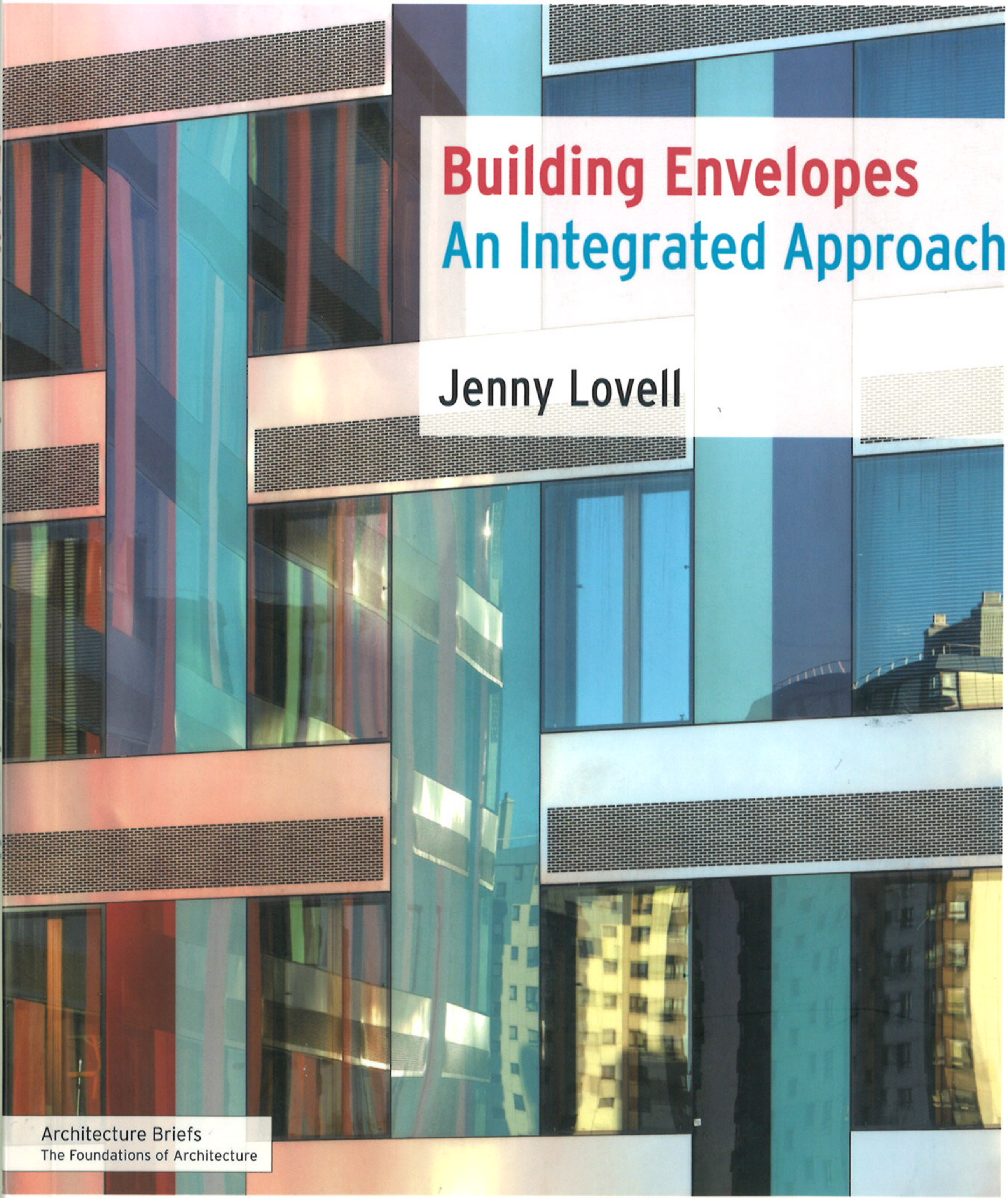

Building Envelopes

An Integrated Approach

Jenny Lovell

Architecture Briefs
The Foundations of Architecture

Far from being just a simple outer wall or decorative element, a building's envelope determines its climate control, degree of energy performance, and relationship to context. There is an urgent need for architects and allied professionals to gain a greater understanding of how materials and technologies can be applied to building envelope design to meet both aesthetic and performance requirements.

Building Envelopes, the newest volume in our Architecture Briefs series, is a process-based toolkit that advocates designing building envelopes in an integrated way, where appearance, use, context, energy performance, structure, and cost are inseparable and considered together. Featuring clearly written texts, original diagrams and sketches, and striking photographs, *Building Envelopes* illustrates how these elements can be combined to create cost- and energy-effective, yet aesthetically pleasing, enclosures.

Jenny Lovell has been critically engaged in the design, development, and application of building envelope strategies in the United States and England for the past fifteen years. Lovell is an assistant professor at the Graduate School of Architecture and Urban Design at Washington University in St. Louis and is registered as a member of the Architects Registration Board UK (ARB) and the Royal Institute of British Architects (RIBA).

Architecture Briefs is a Princeton Architectural Press series that addresses a variety of single topics of interest to architecture students and professionals. Field-specific and technical information, ranging from hand-drawn to digital methods, are presented in a user-friendly manner alongside basics of architectural thought, design, and construction. The series familiarizes readers with the concepts and skills necessary to successfully translate ideas into built form.

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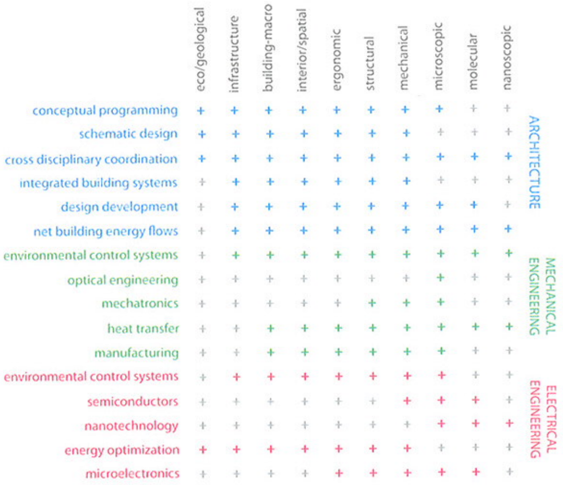
diagram is an attempt to document everything that influences and contributes to the successful engineering of a facade. Two bubbles—"Drawings/ Models" and "Specifications"—are enclosed within the ring of subjects to acknowledge that all these influences are ultimately captured in a set of documents. These are passed to the contractor—shown on the left-hand side of the diagram—and the design is then expressed in terms of the materials and systems available or required and, again, represents a host of considerations. Importantly, the interfaces between all systems should be carefully considered and coordinated before the contractor fabricates, tests, and installs the facade.

Associations

Another way of considering the format of interdisciplinary relationships is as a matrix relating to the scale at which disciplines work; one that is not based on a linear process but relates to associated subject fields, where the density of concentration would shift depending on the specific circumstances of a project. Thinking laterally across fields and understanding each specialist's scale of operation can greatly enhance the possibility of association. For example, a material scientist might be working at the molecular scale and an environmentalist at the scale of a whole ecosystem—depending on the specifics of the project, the relationships of these scales of investigation can allow new possibilities for an integrated design. |2 To enable real invention, we need to make a paradigm shift from the business-as-usual multidisciplinary and interdisciplinary team structure to transdisciplinary ways of working on a team.[1] Transdisciplinary work is a far more fluid process with shared responsibility.

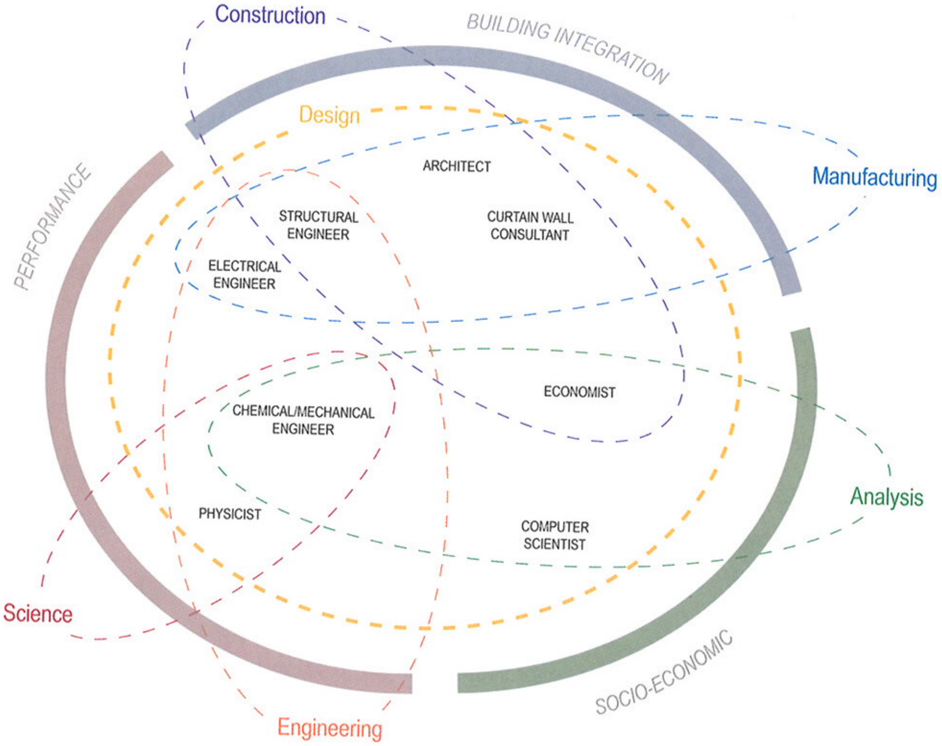


	eco/geological	infrastructure	building-macro	interior/spatial	ergonomic	structural	mechanical	microscopic	molecular	nanoscopic	
conceptual programming	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	+	+	ARCHITECTURE
schematic design	**+**	**+**	**+**	**+**	**+**	**+**	**+**	+	+	+	
cross disciplinary coordination	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	
integrated building systems	+	**+**	**+**	**+**	**+**	**+**	**+**	+	+	+	
design development	+	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	+	
net building energy flows	+	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	
environmental control systems	+	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	MECHANICAL ENGINEERING
optical engineering	+	+	+	+	+	+	+	**+**	+	+	
mechatronics	+	+	+	+	+	**+**	**+**	**+**	+	+	
heat transfer	+	+	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	
manufacturing	+	+	**+**	**+**	**+**	**+**	**+**	**+**	+	+	
environmental control systems	+	**+**	**+**	**+**	**+**	**+**	**+**	**+**	+	+	ELECTRICAL ENGINEERING
semiconductors	+	+	+	+	+	+	**+**	**+**	**+**	+	
nanotechnology	+	+	+	+	+	+	+	**+**	**+**	**+**	
energy optimization	**+**	**+**	**+**	**+**	**+**	**+**	**+**	+	+	+	
microelectronics	+	+	+	+	**+**	**+**	**+**	**+**	**+**	+	

2| Created by the Center for Architecture Science and Ecology (CASE), this transdisciplinary diagram shows which disciplines participate in different scales of building research development. The y axis shows activity range specific to discipline (outlined on right, in detail on left), while the x axis shows which scale they are working at. This diagram was developed to represent the team-working relationships for the Integrated Concentrating (IC) system (see pp. 94–95).

Deep Collaboration

The building industry pretty much works in a multidisciplinary way now—participants and their input

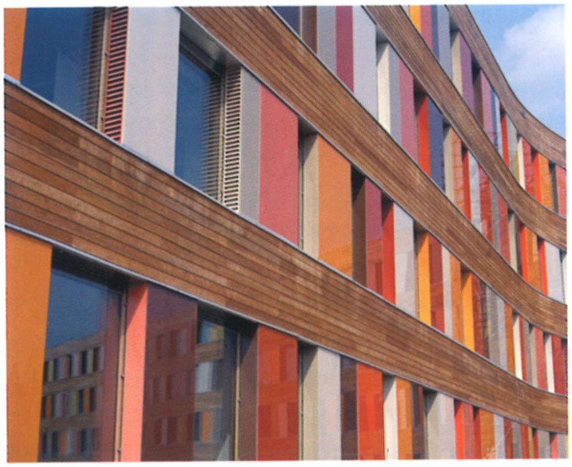


3| Transdisciplinary team integration as mapped by CASE for the development of the IC system. This shows the fluid nature of transdicsiplinary teamwork, where the problem brings everyone together through the many crossovers in the design process.

are tracked in clear, distinct categories, primarily related to liability and responsibility—to allow for finger pointing if anything goes wrong. This structure of responsibility and control is inhibiting, and it keeps design teams from pushing boundaries. Integrated design through interdisciplinary practice is a collaboration developed across a team—for example, when a lighting engineer works with a facade engineer to maximize daylight use and control at the perimeter of a building. This kind of interdisciplinary team structure is considered "best practice."

Transdisciplinarity, however, is an approach that is hard to realize in the building industry as it currently operates, because it requires levels of trust from all parties, new kinds of teams, and new legal relationships. Transdisciplinarity "recognizes the role of values in inquiry, [and] rather than attempting to suppress or 'bracket' them, it engages

9| Office windows opening onto the central atrium, Federal Environment Agency, Sauerbruch Hutton, Dessau, Germany, 2005

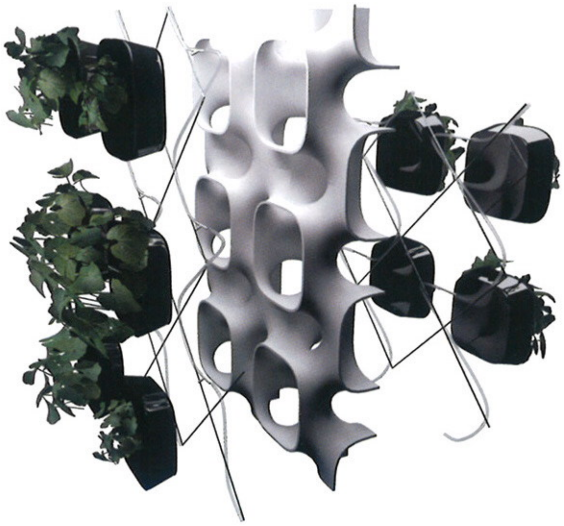


10| View of the external building envelope with air intake vents, Federal Environment Agency, Sauerbruch Hutton, Dessau, Germany, 2005

same principle can be seen in low-rise buildings. For example, architecture firm Sauerbruch Hutton's Federal Environment Agency building in Dessau, Germany, not only has a narrow plan allowing for cross ventilation through offices, but also includes a central courtyard as a non-conditioned buffer zone. |**8-10**

Mixed-mode systems employ a combination of natural and mechanical ventilation systems. When external conditions are favorable, windows can be opened for ventilation, and air-conditioning is used only as needed—when external conditions are too hot, humid, or noisy, or when there are infrequent additional heat loads such as more people than usual in a meeting space. This combined system can be coordinated through sensors feeding information to a building management system (BMS) or have user overrides for direct control. A study by the Center for the Built Environment (CBE) states that "research has found that building occupants prefer a wider range of indoor thermal conditions when they are provided with some measure of personal control,"[2] and energy consumption can be greatly reduced by only relying on mechanical systems when really needed. For example, in St. Louis, Missouri, most buildings are mechanically conditioned, but for approximately two-thirds of the year external conditions are sufficiently favorable to allow for natural ventilation if the building envelope is managed correctly.

Airflow depends on design factors, location, time of day, and season. We expect windows to be a source of both daylight and air. Decoupling or reconfiguring air intake and extraction from visual contact and view can allow greater control of airflow through a building's envelope (as in the Sauerbruch Hutton buildings described in this section). Strategies such as nighttime cooling of a space through the opening of windows need building envelopes that incorporate insect and rain screens, security measures,



11| A diagram of the Active Phytoremediation System (APS), developed by the Center for Architecture Science and Ecology (CASE) at Rensselaer Polytechnic Institute, shows its central air plenum and modular inserts of plant material.

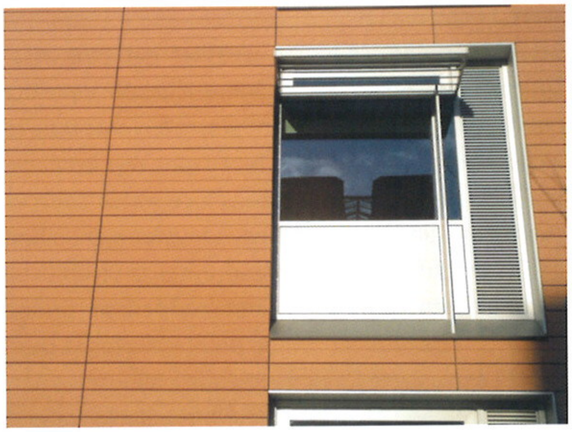
and robust mechanisms, but they also fundamentally need to be operated effectively, which requires the education of building users well beyond initial design and construction.

Air: Possibility |11

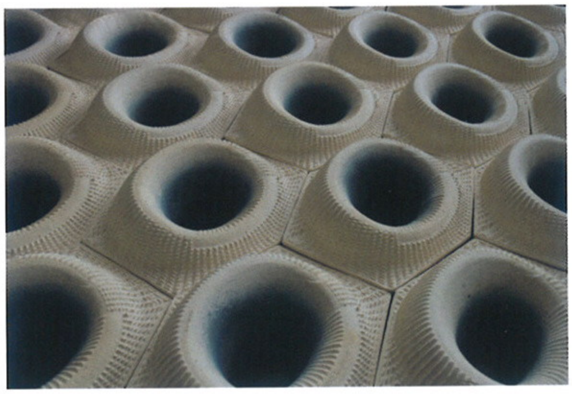
The Active Phytoremediation System (APS), developed by the Center for Architecture Science and Ecology (CASE) at Rensselaer Polytechnic Institute, is a biomechanical hybrid system that improves indoor air quality while decreasing both the energy consumption and exposure to external air pollution associated with conventional air-conditioning systems.[3] The APS operates by amplifying the air-cleaning capacity of common plants by over two hundred times. It does this by actively drawing air from within the building through the roots and rhizomes of the plants, where pollutants are then trapped and digested within the system before the air is redistributed to occupied spaces. The APS is composed of optimized modules that house a variety of plant types in hydroponic cartridges.

Due to its modularity, the system is highly scalable, and it could be architecturally integrated into a wide range of building sizes and typologies. The module is a product designed for disassembly and recycling that capitalizes on low-cost, high-tech emerging manufacturing techniques to improve the potential for adaptable reuse in multiple architectural applications.

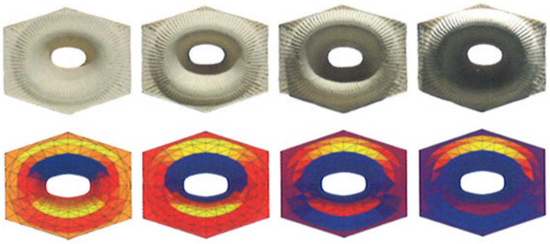
The APS is targeted to reduce a significant number of health risks associated with SBS through actively removing volatile organic compounds (VOCs), particulate matter, and other biological and chemical pollutants from internal air, while introducing humidity to heated interiors during the cold season. It also dramatically lowers a building's overall energy consumption by reducing the need for fresh-air intake while also limiting exposure to external urban-air pollutants, such as ozone.



8| A window unit at the Faculty of English, consisting of a fixed panel of glazing with fixed shading above and a side-opening ventilation panel protected by weather-shielding louvers. Each window unit sits within an opening in the masonry (block or concrete) wall. The wall was first waterproofed and insulated on the outside, then faced with a terra-cotta rainscreen system.



9| The Advanced EcoCeramic Envelope System consists of ceramic units made using low-tech, generic, and readily available ram press production methods typically employed in china plate-making.



10| Computer simulations of the EcoCeramic System depict the relative transfer of heat through the modules.

low-impact and less-energy-intensive alternatives. The Advanced EcoCeramic Envelope System seeks to fill the need for a system developed from abundant materials that can meet demanding performance criteria.[2] This envelope system has the capacity to locally mitigate arid climates into habitable thermal ranges through passive cooling techniques.

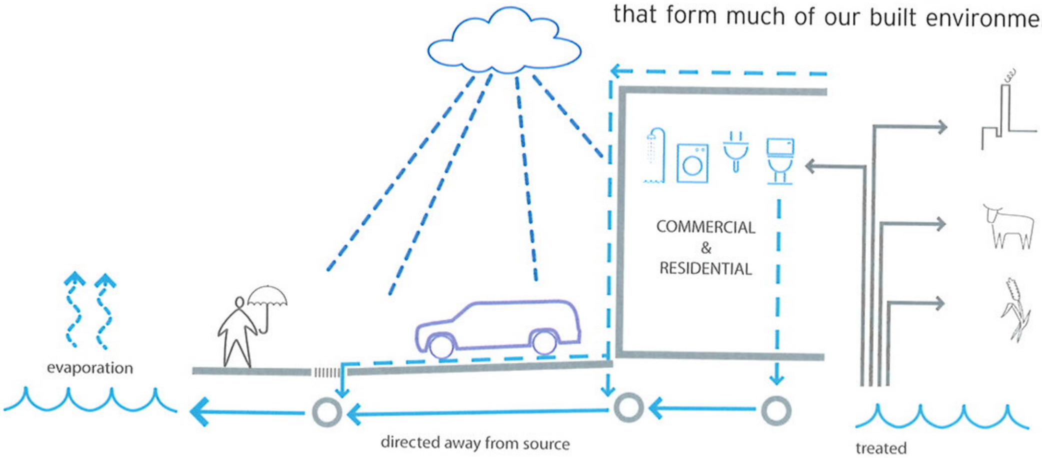
The EcoCeramics are developed from earthenware clay—a readily available material that can be infinitely reclaimed into high-quality ceramic materials. Clay is produced by the natural forces of erosion on feldspar minerals, which make up the majority of the Earth's crust. The mineral compositions of EcoCeramic are modified for strength and porosity with natural additives and fibers to meet design criteria depending on application, and optimized through thermodynamic modeling and innovative design-development tools in order to employ pattern, texture, coating, and color to manifest different thermal performance results and architectural experiences. Surface strategies from CAD/CAM procedures precisely form the EcoCeramic to provide self-shading and to disrupt airflow over a surface, minimizing heat exchange with the thermal environment and allowing for internal temperatures to maintain greater stability.

In the Advanced EcoCeramic Envelope System, low-tech ceramic manufacturing technologies are combined with computer-generated geometric modules that are specifically calibrated to interact with varying daily and seasonal movements of the sun and are aggregated into complex surface patterns.

Water:
Systems and Collection

Water: Problems |1

Global warming, changing weather patterns, irresponsible planning, increased suburban development, inefficient systems, and waste all contribute to a water supply crisis that is faced globally. Available groundwater is limited and surface-water sources cannot support increased development and demands. Additionally, treated water is often used in circumstances where it is not required—according to an EPA handbook, "While potable water is used almost exclusively for domestic uses, almost 80 percent of demand does not require drinkable water."[1] Water is a valuable commodity, yet it is frequently wasted on runoff from the large, nonporous surfaces that form much of our built environment. Typically, this potential water resource is directed away on a linear path—it is piped and discharged into streams, rivers, lakes, and oceans rather than recycled to replenish local water sources. The direction, retention, and detention of water are commonly mismanaged causing strain on insufficient or nonexistent municipal systems.



1| Water: problems
The potential of rainwater collection or local management is frequently lost by allowing water runoff from large areas of nonporous building surfaces, including building envelopes.

The vast majority of building construction problems are related to water in some way. At the scale of building envelope assemblies, water can erode, rot, and cause mold. The practice of "face-sealing" water out of building envelopes (where a waterproof barrier forms an envelope's outer layer to block any

Water: Potential |4

The integration of infrastructure systems, landscape, and buildings is essential in order to control, conserve, and reclaim water. By managing water locally at the scale of the site, pollution and runoff can be mitigated and groundwater can be recharged. This could also provide an amenity for building users and a habitat for flora and fauna.

Building envelopes constitute a whole-building surface condition, from roof to landscape (hard and soft) and beyond. Depending on the specific context and location of a project, its water-strategy approach will have different requirements. In an arid climate such as Arizona, where water is scarce, collection and reuse will be priorities, whereas in a wet climate such as Kuala Lumpur, management of humidity and water flow take precedence.

Water can be engaged in a positive way to suit site conditions and climatic opportunities. A body of water adjacent to a building can act as a thermal storage device to impact the microclimate around the building, store energy interseasonally, or act as part of a site's water-management system, as might be found in a reed bed or conditioning lake. Water evaporating into warm, moving air will cause a cooling effect before the air enters a building and improve interior comfort levels by reducing the resultant temperature.

An inch of rainfall can produce six hundred gallons of runoff per one thousand square feet of roof.[4] There is a huge potential for horizontal and vertical building surfaces to be porous and act as on-site filters and collectors of water (e.g., green or brown roofs) rather than relying on piped drainage systems. For a building's vertical surfaces, the percentage of catchment potential (area that can capture water runoff) is lower, depending on envelope profile, rainfall, and prevailing winds, but they should still be part of an overall catchment calculation. The harvesting of rainwater from built surfaces in order to reduce storm runoff and allow reuse on site requires a relatively low capital cost. These harvesting systems identify a catchment area, a means of conveyance from this area (driven by gravity), a storage system (optional), a water treatment system (also optional), and a means of conveyance to the local end use (gravity or pump).[5] Although less rainwater falls on the vertical surfaces of a building, all of the above require direct coordination with—and can be enhanced by—the building envelope's design, so that water is addressed at the scale of the immediate site.

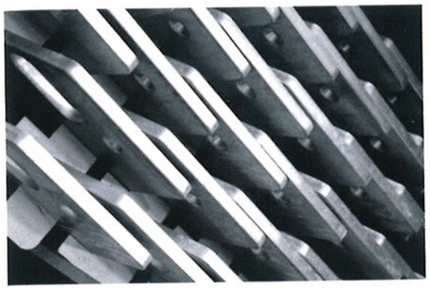
Sustainable drainage systems (SUDS), an alternative approach to piped drainage systems, imitate natural drainage processes with characteristics of storage, slow conveyance, and volume reduction.[6] Every consideration for SUDS is site-specific, and is dependent on soil type, location in the watershed, and local legislation. SUDS aim to reduce both the rate and the volume of water runoff from a building, as well as treat water to remove pollutants as close to the source as possible. A number of techniques can be implemented as SUDS strategies, such as green roofs, porous paving, and retention ponds.

5| The Solar Building Envelope System for Water Recycling, Purification, and Thermal Control purifies water in hot and arid climates.

Water: Possibility |**5**

The Solar Building Envelope System for Water Recycling, Purification, and Thermal Control is a building-integrated solar-absorption strategy for a hybrid, interconnected system of on-site water recovery and occupant comfort control in hot, arid climates.[7] The modulated facade system plugs into a building's infrastructure to allow solar-thermal water pasteurization treatment, providing hot water for distribution to multiple gray-water applications in the building, significantly offsetting demands for water supplies and thermal energy requirements.

The passive, nontracking (i.e., fixed) system is a component assembly, composed of volumetric



8 Bespoke aluminum cladding components await assembly in a factory making unitized cladding panels for Liftschutz Davidson Sandilands' Charlotte Building (see pp. 140–47).

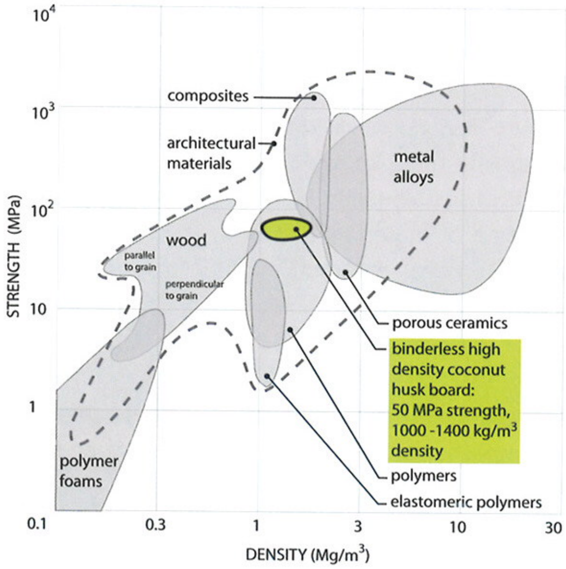
9 Precast concrete cladding components were fabricated in Belgium and assembled in Poland to make unitized cladding panels for Allies and Morrison's Institute of Criminology (see pp. 116–23).

installation, occupation, and disassembly processes. Digital technologies such as building information modeling (BIM) present tools to enable dialogue between designers, industry (suppliers and fabricators), installers, and facilities management.

Fabricators and contractors who are brought into the design process not only constructively contribute to the discussion of buildability, they also bring with them knowledge of the supply chain. In terms of sustainability, this is a way of reconnecting sourcing of materials to the design team without the traditional contractual obligations of explicit specification.

In his book *Buildability in Practice*, Ian Ferguson states that "Buildability is concerned with... putting together assemblies and sub-assemblies, often in bad weather and at all seasons of the year, when hands are frozen and legs are knee deep in mud," and that regardless of developments in prefabrication, site work will always be part of the reality of building.[5] This is true, but developments in computer-aided design and manufacturing (CAD/CAM) in particular have allowed for much more off-site fabrication and assembly of building envelopes. Automated fabrication has enabled more complicated assemblies and specialized integration for unitized systems to be built in the controlled environment of the factory in more efficient ways.

While ultimately system and material applications for building envelopes must be appropriate to the context of the design, advances in material science for composite materials, coatings, and films are enabling specified materials to work harder to meet performance criteria. Professor Paul J. Donnelly and his team at Washington University in St. Louis are researching a holistic approach to the use of phase change materials (PCMs) as part of building envelope and systems performance.[6] PCMs store and release energy as they change state from a liquid to solid and vice versa. They have been used in clothing and product design for their thermal comfort properties but have been slow to enter the building market due to affordability and application. By "sucking up" unwanted heat in an internal space, a PCM can play a part in holding on to solar heat gain, delaying release in order to limit discomfort, reduce peak loads on systems, and potentially utilize the thermal energy at a later time when it is needed more. This material application could bridge the gap between aesthetics and comfort by being inserted into the building envelope assembly or internal wall construction.



10| When binderless, high-density Coconut Husk Boards are compared to typical values of other material categories, it is found that their strength is comparable to or exceeds that of most architectural wood products.

11 |Coconut husks, the raw material for Coconut Husk Boards.

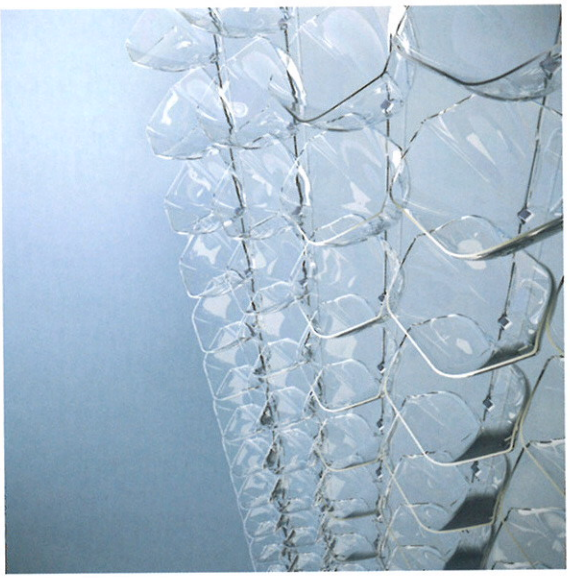
12 |Coconut Husk Boards, developed by a team at CASE, are made from post-agricultural waste and can be fabricated at multiple scales and configurations.

Materials: Possibility |**10-12**

A team at Rensselaer Polytechnic Institute's Center for Architecture Science and Ecology (CASE) are investigating the viability of developing structural materials from the post-agricultural waste of coconut husks, which can be milled and manufactured into multiple low-cost building products for use in tropical hot and humid climates.

Coconut Husk Board promises to be a viable and high-performing substitute for imported wood-based products, especially in the tropics, where a substantial volume of husk from coconut production can be reclaimed and processed into building materials at an industrial scale.[7] Intrinsic lignin biopolymers in these husks eliminate the need for synthetic binders in high-performance sheathing boards.

When manufactured as a desiccant board, the coconut husk absorbs water vapor, creating a drier, more comfortable internal environment. The proposed building-prototype designs integrate Coconut Husk Boards with passive cooling strategies to provide greater comfort, with the potential to reduce energy consumption in a broad range of housing types.



4| The Integrated Concentrating (IC) solar facade system—designed by Anna Dyson (CASE/RPI), Michael Jensen, a mechanical engineer at RPI, and Peter Stark, a Harvard physicist—maximizes the capturing and utilization of solar energy through a building envelope.

5| The facade's modules are made of borosilicate glass and attach to a glass tubular structural system.

capitalizes on the structural components, encasements, and maintenance schedules of existing facade systems and uses minimal and inexpensive materials.

PV panels currently operate at a 15 to 20 percent efficiency rate. The IC system is far more efficient, though, because it tracks the path of the sun to maximize energy transfer and uses concentrating solar cells, which currently have a 35 percent operating efficiency rate, for electrical production. Through further research, these solar cells are projected to have the potential of more than 50 percent efficiency in the future. Additionally, approximately 40 percent of the remaining waste heat is recovered from the building facade and converted into high quality heat (a higher temperature form of heat that can be transferred further distances with greater efficiency), which can power cooling systems. In this way, the IC system inverts conventional models of dealing with heat and light that shine on buildings because it does not reject the direct solar gain to the building, but rather it transforms the qualities of the incoming energy and redirects the flow so the energy can be fully harnessed and utilized. Instead of using opaque shading surfaces, transparent modules actively concentrate, use, and remove solar energy before it is transferred through the building envelope as heat, converting a low-quality, diffuse energy source into a higher quality form that can be used to drive building systems such as cooling.

The architectural integration of the IC system ensures an efficient transfer of electric and thermal energy into interior applications while reducing solar gain and enhancing daylight penetration. It also allows for the possibility of shading or daylighting a space through transparent surfaces by redirecting direct solar beams while allowing diffuse light to flood interior spaces, Energy production projections for the IC system show cost payback periods that are substantially below those of existing solar-energy systems.