The Art of Science

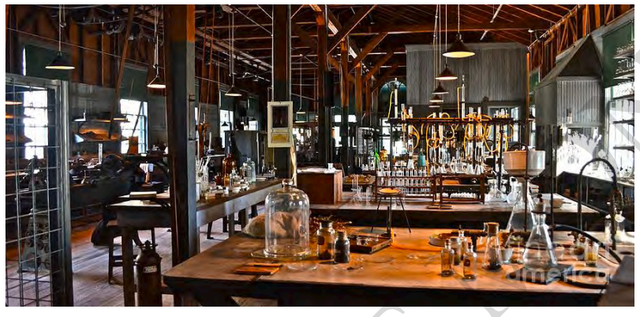
James H. Collins, Jr.

Payette sees the laboratory as a cultural institution as much as a scientific one. It is a place of imagination, not merely of procedure. Accordingly, its architecture must support the imagination, and our practice is dedicated to that end.

Despite society's fascination with the lone genius, science in the modern era (like architecture) is a collective endeavor. In 1885, author Sarah Knowles Bolton wrote of Thomas Edison,

> When one of his inventions failed—a printing machine—he took five men into the loft of his factory, declaring he would never come down till it worked satisfactorily. For two days, and nights and twelve hours—sixty hours in all—he worked continuously without sleep, until he had conquered the difficulty.

We can't help but wonder how much the other five men slept. For the architect, the more salient question is: What was the quality of their experience during those long hours? As it happens, we have some idea.



Thomas Edison Research Laboratory, 1876

When Edison's research laboratory opened in Menlo Park, New Jersey, in 1876, it was a simple, rectangular loft, with large windows for natural light—it predated, after all, the electric light bulb, which was perfected there. The windows opened for ventilation. Apparatuses weren't tethered to elaborate mechanical systems, but placed wherever was most convenient for the researchers. It was a workshop, not so different from the labs you see in paintings from the sixteenth century. Its roots were in the person and the science, with almost no engineering of the environment. It was a humane space. The same was true of turn-of-the-last-century academic teaching spaces for science: they were first of all well-proportioned, daylit rooms; technology barely shaped their design or expression.

Following World War II, things changed. The war had been won on the back of the atom bomb, developed in top secret laboratories, windowless to keep out prying eyes, compartmentalized so that only a very few knew the whole of what was going on. With the outbreak of the Cold War and the ensuing space race, technology became a driving force. Air conditioning arrived around the same time, and thinking about buildings of all sorts fundamentally changed. The laboratory changed dramatically. It came to be designed not by the researcher or the architect, but by the mechanical engineer, for the efficiency of the technical systems. Optimized around machinery, it was more like a factory, with a bulky mechanical core and ranks of fume hoods crowding out the windows. These Sputnik-era labs were closed and cramped, opaque and not at all conducive to collaboration.

Restoring the Academic Loft

This model predominated throughout the 1950s and, '60s and into the 1970s. Tom Payette first challenged it in the design of the Sherman Fairchild Biochemistry Laboratory at Harvard in 1981, reintroducing natural light and views, both to the outdoors and within the lab itself, so that the researchers could see one another at work. His goal was to make a place that would lift, rather than dampen, the human spirit—a place where scientists would enjoy working. This remains the underlying goal of all of Payette's work.

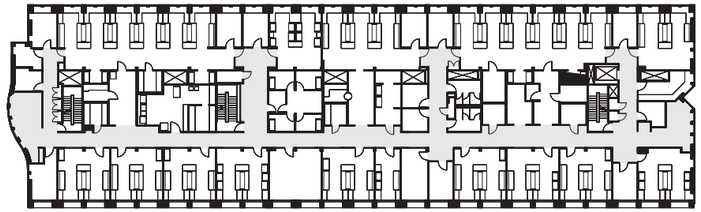
To accomplish that goal, Tom reimagined the relationship between lab spaces and the mechanical systems

Harvard University, Sherman Fairchild Biochemistry Laboratory, 1981

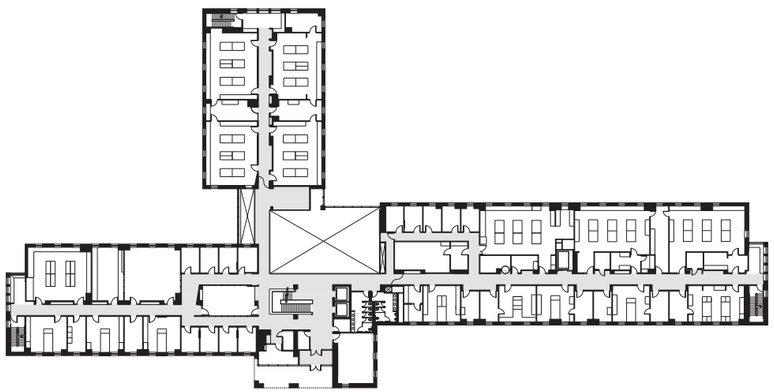
serving them. He moved the fume hoods to the interior and replaced the continuous, central mechanical shaft with a series of smaller shafts, between which the interior lab walls were glazed, floor to ceiling. The labs were fully transparent to the corridor, so that the connection to the outside carried all the way through the building.

Transparent to light and views, Sherman Fairchild also revealed its mechanical systems; there were no hung ceilings, no furred-out surfaces. Its concrete structure was left exposed, complemented by warm, wooden casework, rather than gray metal. It was the first lab to express its elements honestly and the first to dispel the chill, Cold War mentality.

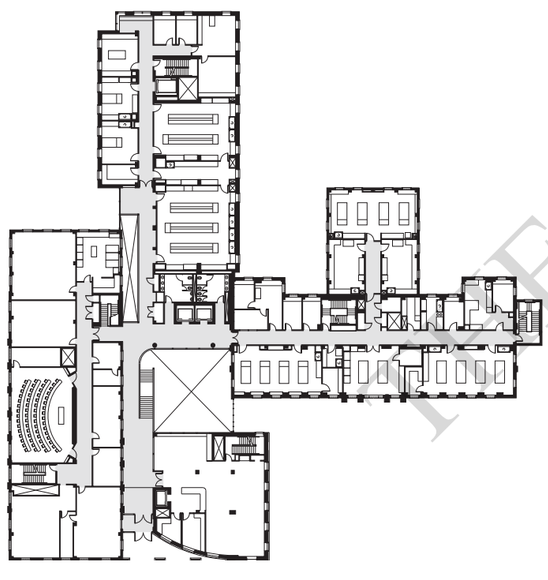
Payette's next advance was to combine the uncomfortably small lab spaces, which were the postwar norm, into continuous, open labs, shared by several principal investigators. It took more



Princeton University, Lewis Thomas Laboratory, 1986



Middlebury College, McCardell Bicentennial Hall, 1999



Washington and Lee University, Science Center, 1997

than simply removing walls. Architecture always requires an understanding of the relationships between natural phenomena, people, and the building itself. Technically complex buildings like labs are particularly demanding. In them, the control of air movement is critical, both for the safety of researchers and to avoid cross-contamination of experiments. To effectively control air movement in the open lab required invention: the development of precisely configured and strategically placed fume hood alcoves. The means may have been prosaic, but the result was inspiring: a bright, open, collaborative space, shaped not for the equipment but for the people.

We first realized the open lab in the Wellman Research Building at Massachusetts General Hospital in 1985. The following year, in Princeton University's Lewis Thomas Laboratory, we combined the open plan of Wellman with the transparency, expression of systems, and warmth of materials of Sherman Fairchild. To the long-diminished laboratory typology, Lewis Thomas reintroduced the energy and generosity of the academic loft.

Interaction and Discovery

In an open lab, less space is needed for corridors. At Lewis Thomas, we put some of that saved space to a novel use: we extended the ends of the remaining corridors into cozy lounges, comfortably furnished and lined with blackboards. It is now common practice for lab buildings to incorporate informal spaces for casual interaction among scientists; Lewis Thomas was the first institutionalized instance of it.

We have similarly reworked undergraduate teaching spaces to enhance interaction between faculty and students. Up until the mid-'90s, undergraduate science buildings were typically organized with large teaching labs on the entry floor and faculty offices on upper floors. Faculty research labs were rare, especially in small liberal arts colleges.

In the 1990s, many of these smaller colleges began to introduce research projects for seniors, to give them a taste of graduate school and to strengthen their admissions prospects. In two projects in the late '90s, one for Washington & Lee University (1997) and one for Middlebury College (1999), we dramatically reorganized the undergraduate science building to support this change in curriculum. At Washington & Lee, we clustered teaching labs, research labs, and faculty offices by discipline, which facilitated not only formal instruction but also informal learning. In particular, lower division students were exposed to the work of the seniors, from whom they could learn a great deal.

We took this idea further in McCardell Bicentennial Hall at Middlebury, where four arms radiate out from a central great hall. The relationship of the arms to the center is something like that of the arms of a starfish: there's an ambiguity about where the body stops and the arms begin. In McCardell Bicentennial Hall, each arm has a distinct program—wet labs in one, dry in another, with, again, the collocation of teaching labs, faculty labs, and offices—but they become less specific as they near the center, encouraging interaction between disciplines. The scheme mirrors the undergraduate experience of gradually focusing in on a specific area of study.

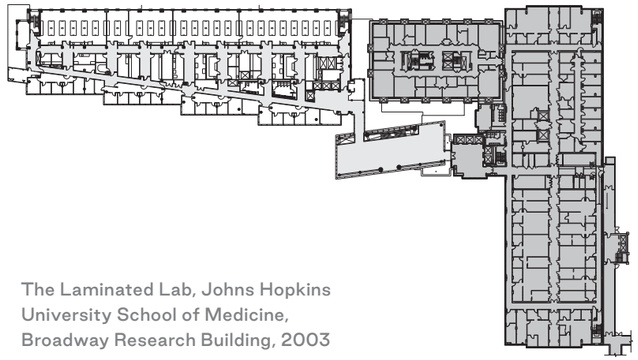
Efficiency and Social Geometry

McCardell Bicentennial Hall is also highly sustainable, not only in operation but also in construction. It was such a large building for the state of Vermont that it became the catalyst for the certified lumber industry in the state. As the first undergraduate science building to earn *R&D* magazine's Lab of the Year Award, which typically goes to major corporate research labs, it has

become a much-emulated model.

Laboratories are expensive buildings, so we continually seek efficiencies of space, structure, materials, and systems. These efficiencies conserve resources and lower costs, but their ultimate goal is to make the building more limber, to permit richer, more productive social geometries. Such geometries—the ways that people see and meet one another, both in the midst of their work and in more casual encounters—affect, sometimes profoundly, the progress of their investigations.

Social geometry is three-dimensional. In Mass General's Wellman Research Building, for example, a structural system of less than normal depth enabled us to align the floors with the existing, adjacent Edwards Building, so that the labs in the two could operate as larger realms of collaboration. A similar strategy allowed us to carve out space for social interaction in George Washington University's Milken Institute School of Public Health in 2014.



The Laminated Lab, Johns Hopkins University School of Medicine, Broadway Research Building, 2003

The Layered Laboratory Concept, National University of Ireland Galway, Biosciences Research Building, 2013

Questioning Long-Held Assumptions

The greatest opportunity for resource conservation in labs is energy use. Laboratories, along with hospitals, are among the most energy consuming of all building types. Making a sustainable laboratory is one of today's critical challenges, one we are working hard to meet. In 2011, we established our Building Science Group to enable us to do it better, by integrating research and design. We conduct intensive investigations, shadowing researchers and metering actual energy use. We've discovered that many of the energy design loads (heating, cooling, electric) used in the industry are too high; they push you into less-sustainable systems. That's the first way to reduce energy use: get the loads right.

The optimization of HVAC systems is not merely a matter of energy savings, but also of human comfort, and in fact the two are intimately entwined. Much of what building HVAC systems purport to do is to create a controlled environment for human comfort, yet the standard of comfort is defined in a psychrometric chart that was determined in the late 1950s, tuned to men in suits, rather than to our present population, more diverse in gender and dress. It is not surprising that most women feel that typical academic buildings are overcooled. Their voice did not contribute to that chart. We now have the ability to develop more detailed models of human comfort that track clothing worn, air temperature and movement, and radiant surface temperature differentials, and we can design systems that respond to this information. Just as the metering of actual power usage for equipment has enabled us to reduce building energy loads, so does the accurate assessment of comfort needs; together, the two reduce not only energy use but also the capital cost of construction.

Systems Differentiation and the Laminated Lab

Thinking of energy consumption as a function of human experience has allowed us to make paradigm-changing advances in laboratory architecture. Wellman's structural innovations were accompanied by an innovation in HVAC systems—separating laboratory heating, served by fan coils, from ventilation. Doing so made both more efficient. More significantly, the concept of separating the two enabled a revolutionary planning strategy, one that has further enhanced the human experience, in what have ultimately become some of the world's most energy-efficient labs.

In 1995, we introduced the "laminated lab," in which the researchers' offices, which had typically been interspersed between lab spaces, are organized as a band on one side of the building. On the other side is a band of labs, with a band of support spaces in between. This arrangement was more cost-effective, because it consolidated the expensive, high-technology spaces on one side and the less expensive office space on the other. At the same time, it gave both office and lab space direct views to the out-of-doors. Other examples of the laminated lab from this period are the Chemistry Research and Life Sciences Buildings at Penn State (2004) and the Life Sciences Building at West Virginia University (2002).

Shadow Studies and the Layered Lab

At the outset of our practice, founding partners Fred Markus and Paul Nocka used time-motion studies and extensive, firsthand observations to develop a detailed understanding of how hospitals worked and how they could be made to work better. We employ similar techniques for laboratories, shadowing researchers engaged in a wide range of activities, spending a day doing what they do, so that we understand it intimately. In recent years, we have observed a gradual change in research practice, driven by increasing reliance on specialized equipment. Whereas researchers had typically spent more time at the lab bench than in support spaces, today they spend more time in the support spaces, where this equipment is housed. When these spaces were used rarely, it was acceptable for them to be in the center of the building, without views. That is no longer the case, so we have introduced another paradigmatic change in layout. In the "layered lab," prototyped in an unbuilt project for Harvard's Allston Campus and first realized in our Biosciences Research Building at the National University of Ireland Galway (2013), the support spaces form an outside band, with the band of open laboratory spaces in the middle, looking through floor-to-ceiling glass to the non-tech-

nical workspace and the outside world beyond. Now everyone enjoys daylight and views.

At the same time, the layered lab dramatically changes the energy profile of the building. All of the spaces that don't use chemicals—the workspace layer—can have a separate, less robust mechanical system. The cost of these systems is reduced, and there's a big jump in energy efficiency. At 143 kBtu/sq.ft., the project at NUIG uses 72 percent less energy than the current baseline set for the 2030 Challenge, and was awarded a national AIA COTE Top Ten Award.

Sense Experience

As we have transformed the planning of laboratories, we have also rethought the details that intimately affect the individual researcher. For the Biomedical Sciences Tower III at the University of Pittsburgh School of Medicine (2005), we developed a modular, adaptable casework system, which allows for ease of reconfiguration. The lab's facilities department can raise and lower the benches and relocate them for better, more cost-effective arrangements, without calling in a contractor.

In our 2011 renovation of Harvard's Sherman Fairchild Biochemistry Building (for which we had designed the first wooden casework thirty years previously), we introduced a task ambient lighting strategy, using very thin strip LEDs as task lights under the shelf of the lab bench, which puts light where the researchers actually need it and reduces the power density in the lab by half. Working with a lighting manufacturer, we designed the fixture, versions of which are now produced by several manufacturers and are being used widely in the industry. The color of the benches themselves is calibrated to reduce eye strain. We treat the interiors of the labs with as much care as the lobby and office spaces, using wood and other materials that aren't only durable but also pleasant. At the Schepens Eye Research Institute for Harvard School of Medicine (2004), we use color in the laboratories to explore the depth of the visual field for scientists investigating the same concept in their research.

The Lab, the Campus, and the Wider World

The material of a bench-top is architecture at its most intimate. At its most expansive is a building's relationship to its near and distant contexts. Today, with society's renewed focus on STEM fields, colleges and universities are investing heavily in academic laboratories, which often play defining roles on the campus. They shape the experience not only of faculty and students in the sciences, but of the entire campus community and, in some cases, the city of which it is a part. This larger context is both natural and cultural, and for us the building is an opportunity to weave connections between the two.

Our recently completed New Science Center for Amherst College (2018), set against the Pelham Hills, anchors the eastern edge of the campus in the landscape. Its transparent commons, a focal point of the new campus greenway, makes its activities visible, inviting interest in the sciences. At Northeastern University, the Interdisciplinary Science and Engineering Complex (2016) is a gateway to the university's new academic precinct, connecting the Fenway and Roxbury neighborhoods of Boston. Its fluid form, sculpted to guide passage between the precincts, is rigorously tuned to dramatically reduce heating and cooling loads—a vivid demonstration of the fusion of design and performance. Its publicly accessible six-story atrium is scaled to serve as the hub of the new precinct.

Knowledge and Freedom

The true measure of a building's success is its ability to support the technical, physical, and behavioral needs of those who use it. From the sensual qualities of a surface to the social geometry of an entire research complex and the campus of which it is a part, human experience drives the disruptive actions of our practice. Introducing transparency, revealing systems, cracking open compartments, proposing new patterns of interaction, we have opened up the laboratory typology as no one had done before.

The art of design for science is knowing the science well enough to identify when such changes can occur, and knowing what the changes mean for the culture of science. The freedom to enact these changes is hard-won, a product of our deep knowledge of the type and our research into building performance and human behavior. Over the past four decades, Payette has freed the laboratory from its postwar claustrophobia, making it once again a place of imagination.