Modularity: An Interdisciplinary History of an Ordering Concept

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In the final decades of the twentieth century, experts in a wide variety of disciplines—such as computer science, evolutionary biology, management studies, and educational theory—introduced the concepts of modular design into their professional discourses and practices. In each of these disciplines, modular systems called for standardized, interchangeable components (or modules) that could be recombined within a predefined system architecture. This article explores the modern history of modularity as it was imagined and applied in two specific settings: the architectural theories of Albert Farwell Bemis in the 1930s and the construction of electronic computers in the 1950s and 1960s. By framing this account as a history of an ordering concept, I hope to persuade information historians to look across traditional disciplinary boundaries and examine the more general set of concepts, strategies, organizations, and technologies that humans have used in their unending efforts to order and make sense of information.

A promising theme in information history is the study of human concepts and strategies to organize and use information—that notoriously abundant and unruly entity. One such ordering concept, *modularity*, has in recent decades become a common strategy for the organization of information within and across a number of professions and scholarly disciplines. The purpose of this article is twofold: to analyze the uses of modular concepts in a variety of professional and disciplinary settings and to demonstrate that information history might be usefully conceptualized as *interdisciplinary* history.

Modularity describes specific relationships between a whole system and its particular components. A modular system consists of smaller parts (modules) that fit together within a predefined system architecture. Modules feature standardized interfaces, which facilitate their integration with the overarching system architecture. A key feature of each module is that it should encapsulate (or "black-box") its messy internal details, thus masking technical, organizational, cultural, and

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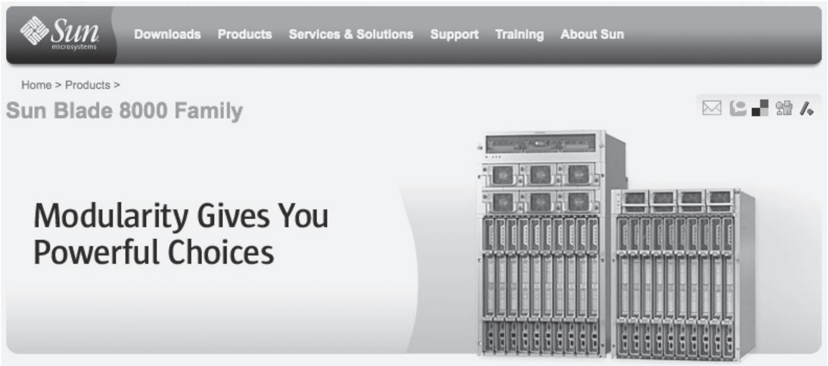

Figure 1. Marketing the power of modularity. Sun Microsystems (accessed October 27, 2011).

political conflicts to display only a consistent interface. The designers of modular systems are therefore able to swap modules in a "plug-and-play" manner, which increases the system's flexibility. Modularity, in a general sense, is therefore a means for confronting and managing complexity in a dynamic and systemic context.

The broad interdisciplinary appeal of modularity can be seen in the great variety of modular discourses that have arisen in the past few decades. Historians of information technology may be most familiar with modularity in computer hardware and software, organizational design, and managerial strategies for information industries. Authors writing in these contexts use the term to describe existing systems, but they also recommend the "power of modularity" (to borrow the subtitle of *Design Rules*, an important text in management literature) to engineers and executives. The concept possesses a kind of inner convincing power for them: analysts of modularity in information systems are usually advocates as well.[1]

Beyond the realms of computer technology and strategic management, the term "modular" also figures prominently in debates within the natural and human sciences among psychologists, biologists, and neuroscientists. In management literature, modularity appears as an expression of power relations in human-built systems, both technological and social.[2] In the natural sciences, however, it is more difficult to conclude that modularity is inherently a strategy for a rational system architect to exercise power and black-box politics. The debate that began with Jerry Fodor's 1983 book *The Modularity of Mind* raised more fundamental questions, including those concerning the structure of the human brain, human capabilities such as speech and rational choice, and, more generally, evolutionary development of the complex systems that permeate the natural world.[3]

Modular concepts have also been applied in disciplines that seem at first glance to be completely unconnected to the technically sophisticated realms of computers, management, and biology. A quick consultation with our twenty-first-century information-ordering tools—including JSTOR, Google Scholar, and the online catalog of the Library of Congress—reveals that the language of modularity appears in diverse fields, such as education, prosthetics, orthopedic implantation, literature, crocheting and knitting, newspaper and magazine design, intellectual property law, and even the transformation of American military capabilities in the twenty-first century.[4]

How can we make sense of this bewildering variety of disciplines and practices that seem to be united only by their affinity for the buzzword "modular"? First, the timing is significant, since all of these experts adopted modular discourses after the mid-1970s. Second, different communities of technical and aesthetic professionals all used the term "modular" to signal their introduction of a conceptual innovation into an already well-developed field. People who needed tools to conceptualize and master complexity found modular concepts to be powerful and intuitive solutions. Modularity became a way of seeing, knowing, and ordering.[5]

This article represents a starting point in a larger project to develop an interdisciplinary history of modularity. I begin with definitions of "modular" from the *Oxford English Dictionary* to underscore the flexibility and contingency of the word and its meanings. The remainder of the article explores two key developments in the twentieth-century history of modularity. The first example comes from modular practice within the midcentury American housing and building industries. My account focuses on the American industrialist Albert Farwell Bemis and the housing reformers he inspired to experiment with modular standards—centered around a four-inch cubical module—as a way to rationalize building methods. The second example builds upon a detailed account of the history of modularity in the early computer industry that appears in *Design Rules: The Power of Modularity*, a book by Harvard Business School professors Carliss Baldwin and Kim Clark. Their study of modular concepts within the design of IBM's System/360 is insightful, but I will argue that it is incomplete as a work of history because it understates the breadth and significance of modular discourse in electronic computer systems that predate the System/360.

Three methodological considerations guide my inquiry. First, I do not want to get carried away in the euphoria of modularity or make normative claims about its practical utility for information historians or other information professionals. Instead, my primary goal is to explore the history of specific modular systems and, within those histories, to critically examine modular discourse for insights on how system architects used modular concepts to order, coordinate, and control. Information professionals who hope to find specific recommendations in this article for adopting the principles of modularity will be disappointed, but they may benefit from my discussion of the advantages, limitations, and diversity of modular practice. Second, I do not use the term "modular" to describe existing systems whose makers did not use it. This decision distinguishes my approach from John Blair's book *Modular America*, which presents American cultural history as a discrete set of modules—including education, literature, music, sports, and religion—that together constitute American culture.[6] Rather, I assume that the power of modularity is tied directly to the language and conceptual frames (or "actors' categories") used by people who deployed the language of modularity and applied modular concepts to new realms.

Third, my account is *interdisciplinary* history because it uses a historical lens to consider how ideas, concepts, and discourses traveled across disciplinary and professional boundaries. Although it is difficult at times to uncover concrete evidence that explains the spread of modular ideas, discourses, and practices from one profession or discipline to another, there is no need to resort to the imprecise and simplistic notion that modular concepts spread because they were "in the air." Intellectual historians such as David Hollinger, Anthony Grafton, and James Secord have developed more nuanced accounts of the circulation of ideas and practices that are embedded in discursive and material contexts. Following their lead, as I examine modularity in different settings I focus on professionals who adopted and adapted the general principles of modularity to bring efficiency and order into complex social and material systems. This approach requires me to fix my gaze across the disciplinary boundaries that professionals erect and historians tend to reify. Disciplinary boundaries are of course significant and deserve continued close attention; but so, too, do the more general sets of concepts, strategies, and organizational schemes that humans have used in a variety of disciplines and professions as they have tried to order and make sense of information.[7]

A History of Modular Systems in the *Oxford English Dictionary*

The *Oxford English Dictionary* (*OED*) definitions of the noun "module" fall into three distinct categories. The first category describes "general uses relating to extent or relationship." Several definitions in this category, now classified as obsolete, date from the late sixteenth and early seventeenth centuries. They include references to a small-scale plan, a physical representation or model, or, for Shakespeare (in *King John* and *All's Well that Ends Well*), a mere image or counterfeit.[8]

The dictionary's second category of definitions documents "chiefly technical uses relating to measurement and proportion." These definitions contain references (again from the sixteenth and seventeenth centuries) to pillars and columns in Roman and Greek architecture; a "standard or unit for measuring" (with examples from the seventeenth and mid-nineteenth centuries); and mathematical definitions—some of which relate to size and proportion and others that are comprehensible only to mathematicians—that date from the late nineteenth century. All of the definitions from the *OED*'s second category indicate that speakers of the English language before the twentieth century used the noun "module" to refer to a size or unit of measurement, usually with some sense of proportion and an implied relation to a larger system.

By the mid-twentieth century, however, the *OED*'s definitions reflected deeper changes in industrial-era technology and language. Its second category of definitions of the noun "module" concludes with "8. A length chosen as the basis for the dimensions of the parts of a building, esp. one to be constructed from prefabricated components, all the dimensions being integral multiples of it. See also sense 9."[9] The *OED* identifies the origin of this particular usage in a 1936 book, *The Evolving House, Vol. III*, by the American industrialist and housing reformer Albert Farwell Bemis.

Bemis's core idea—architectural coordination that combines parts with standard dimensions—provided the foundation for subsequent uses of the word that the *OED* groups into a third category of definitions, "a component of a larger or more complex system." It is only within this third category of definitions that uses of modular concepts from the 1970s to the 2000s—in works of evolutionary biology, pedagogy, military strategy, prosthetics, and so on—cohere and make sense as a whole. In each of these more modern examples, the concepts of complex systems, standardization, and interchangeability overtook size, measurement, and proportion as the core concepts of modularity. The *OED* documents the finality of the semantic transition toward complex systems with its third category of definitions for the noun "module": "9. *gen.* Any of a series of independent units or parts of a more complex structure, produced to a standard design in order to facilitate assembly and allow mass production. More generally: any more or less self-contained unit which goes to make up a complete set, a finished article, etc."[10]

Taken together, the *OED* definitions indicate a breadth and depth of meaning that any comprehensive history of modularity should seek to illuminate. We can set aside the *OED*'s "obsolete" definitions from Shakespeare's era and specific technical concepts from nineteenth-century mathematics and begin a history of modular systems in the twentieth and twenty-first centuries with Albert Farwell Bemis. Through the work of Bemis and his colleagues, we can see how modularity was first industrialized before it was computerized and popularized in the late twentieth century.

Albert Farwell Bemis and the Four-Inch Module

The modernization of the American industrial economy in the early twentieth century provides a context for understanding the historical significance of Bemis's designs for a modular future. During this era, professional engineers and managers extended their power throughout American industrial practice by applying new ideas of systematization, mechanization, and rationalization—in short, order and control. The signature achievements of their work include assembly-line mass production at Ford Motor Company's Highland Park plant in Michigan, the widespread application of management theorist Frederick Winslow Taylor's principles of scientific management, and the science-based innovations that flowed out of the industrial laboratories at General Electric, American Telephone & Telegraph (AT&T), and Dupont.[11]

American engineers after World War I—led by the "Great Engineer," President Herbert Hoover—worried deeply about industries that were not as easily tamed by the managerial and scientific strategies that were so successful for automobiles, electrical power, telephones, and chemicals. The 1921 report *Waste in Industry* featured the building industry as a prominent example of a "backward industry" that was unaffected by managerial hierarchies, professional engineers, and industrial research. *Waste in Industry* cataloged the building industry's problems, including irregular seasonal employment, inefficient management, wasteful use of materials on the job site, and a confounding patchwork of local, state, and national regulations. The social consequences of backwardness were profound: the nation faced a housing shortage in the wake of World War I, but the fractured industry was ill equipped to meet the widespread need for high-quality, low-cost shelter. As depression set in during the 1930s, the housing and building industries remained "sick," "backward," and limited in scale and scope—apparently in defiance of the progressive sweep of science, technology, and professional management.[12]

Various proposals discussed during the 1920s and 1930s to combat problems within the housing and construction industries combined technological and organizational strategies such as industry-wide standardization and factory assembly of building components. Albert Farwell Bemis was one of the more thoughtful and articulate of the advocates for standardization. Bemis began a long and lucrative career with his family's business after earning a degree in civil engineering from MIT in 1893. Early in his career, Albert worked with his father, Judson Moss Bemis, to design and build an ideal manufacturing community in Tennessee, a town they named Bemis, which has since been absorbed into the nearby city of Jackson. Albert eventually served as president (1909–25) and chairman (1925–34) of Bemis Brothers Bag Company, a bag manufacturer that owned factories throughout the Midwest. Albert Bemis became involved with the housing and construction industries after World War I, when he established a holding company for an architectural partnership and several companies that produced building materials such as gypsum, metals, and fibers. His deep fascination with the building industry—especially the housing sector—culminated with his publication of a three-volume treatise, titled *The Evolving House,* between 1933 and 1936.[13]

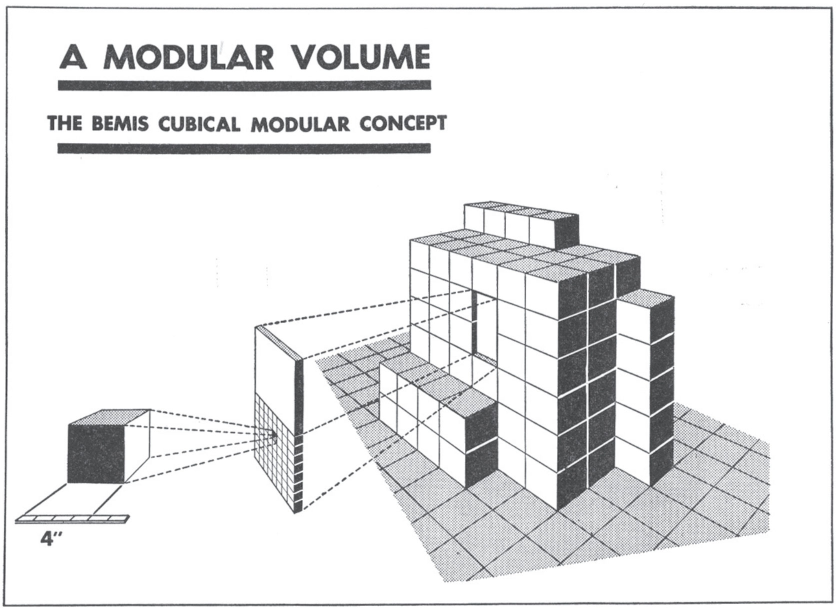

Figure 2. The Bemis cubical modular concept, from "A Modular Volume: The Bemis Cubical Modular Concept," in *Basic Principles of Modular Coordination* (Washington, DC: US Housing and Home Finance Agency, 1953), 5.

Bemis's most original contribution was his insistence that an industry-wide conceptual shift in structural design would lower costs, reduce waste, and increase efficiency. Bemis summarized his careful historical and economic studies of housing in volumes 1 and 2 of *The Evolving House* before turning in volume 3 to the various materials and components—walls, doors, windows, timber and metal beams, and so on—used to build houses. Bemis called for cooperation among architects, manufacturers, and laborers to adhere to a common standard for the dimensions (thickness, length, and height) of building materials. His solution was a theory developed around what he called a four-inch cubical module.[14]

Why Module?

The Bemis module was fundamentally a unit of measure with important (if unacknowledged) origins in classical architecture; it also drew implicitly on the term's nineteenth-century mathematical connotations of size and proportion. In volume 3 of *The Evolving House* (1936) Bemis introduced his modular concept by, in effect, pointing out that it had always existed:

> Like many another fundamental conception, once seen the principle exemplified in the cubical module turns up endlessly. It is found in the weaving process, in tapestry, brickwork, and tiles, as well as in the processes of mass production, the nature of building materials, the rectangularity of the building structure. All these, and the many more things both tangible and intangible which compose our daily environment and in which we find utility, beauty, and satisfaction, are virtually founded on a similar conception. . . . Fifteen years of study, thought, research, and experiment have established for me the soundness of this elementary approach to building structure—the cubical modular concept.[15]

Despite the *OED*'s suggestion that volume 3 of *The Evolving House* was the first text to use "module" in this way, several immediate predecessors exist. The most significant of these is US patent 1,878,367 for "Building Construction," which was awarded to Bemis on September 20, 1932. This was not Bemis's first American patent for "an improved form of building construction," which was also the subject of his patent 1,741,219, awarded on December 31, 1929. But where the 1929 patent used numerical values to specify dimensions, the 1932 patent was the first instance where Bemis used the term “modular” to refer to his plan and the first time he used the notation “M” to represent a standard dimensional measure in architectural drawings.[16]

Why Cubical?

Bemis extended his module in three dimensions (as opposed to a two-dimensional linear module) to add practical utility to the concept. A cubical module, which Bemis represented as “M,” could serve as a fixed standard dimension upon which structural components—doors, windows, walls, ceilings, and so on—could be based. In this new language of structural design, M was four inches, 3M was twelve inches, 9M was thirty-six inches, and so on. “Houses will not be built of modules,” Bemis explained, “but the module must be a practical unit for the specific design of structural parts.” Bemis’s justification turned on three “potentialities” of the cube: volume, symmetry, and surface.[17]

> According to the cubical modular method, therefore, every house member can be designed within a cube matrix. The cube, as a basis of design, provides more than a mere geometric six-sided figure. Within it may be specifically located all the special and particular requirements of structure: dimensions, design, interconnection in any one of the three directions. Through its potentialities as herein reviewed, the cube assures qualities of unity, variety, and symmetry for structures designed in accordance with cubical modular principles.[18]

Why Four Inches?

Bemis framed his choice of four inches as an exercise in inductive reasoning that unfolded over two decades of study and industry experience. His lucid justification also deserves extended quotation:

> A larger module would restrict flexibility in design; a smaller module would require a greater number of units of different dimensions to meet all conditions. There is nothing magical about a dimension of 4″ for the module. It might measure 3″, or 3 3/4″, or 4 1/2″, or perhaps 10 centimeters in countries using the metric system. For this exposition, a dimension of 4″ is selected, because it is the nominal greatest common divisor of the wood-frame house, which represents the bulk of American housing and is the predominant type to which other forms of construction are related.[19]

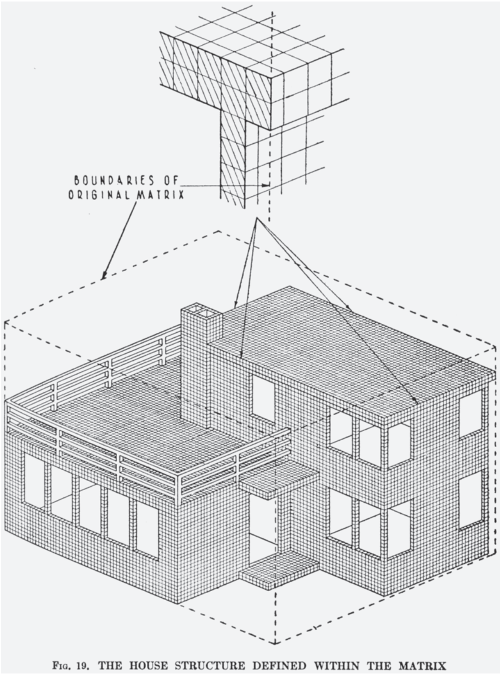

Figure 3. Four-inch cubical modules as a basis of structural design, in Albert Farwell Bemis, *The Evolving House: Volume III: Rational Design* (Cambridge, MA: MIT Press, 1936), 71. *Used with permission of The MIT Press.*

Bemis's plan stood apart from the rationalizing visions of his more famous contemporaries, including Frank Lloyd Wright, Richard Neutra, Buckminster Fuller, and architects associated with the Bauhaus school. All of these architects shared Bemis's interest in mass production, standardization, and prefabrication. Bemis, however, did not think that prefabrication and factory assembly alone could drive the comprehensive and fundamental changes that the backward industry needed. Bemis's cubical modular concept operated both at a more basic level—the dimensional coordination of every building component—and at a higher level of abstraction and ambition. The Bemis "module" was not simply a unit of measure; it was also the foundation of an organizational, social, and ideological proposal that aimed at the transformation of all aspects of the housing industry, from architectural design to component manufacturing to onsite assembly. Bemis thus intended to transform the place of shelter in American life.[20]

In volume 3 of *The Evolving House* Bemis argued that solutions to the housing crisis "must not only take into account the diversity and complexity of materials, but must [also] harmonize the house itself with social demand, productive forces, and the many varieties of type required."[21] This, for Bemis, was the essence of *rationalization*, which he defined broadly as "the ever-continuing, evolutionary process by which an activity, a custom, a technique, an industry is brought up to date, into balance, into harmony—that is, becomes rational with respect to other things. This book is but one small contribution to the process by which the housing industry, at present retarded, will be brought into line."[22]

Bemis believed that the spirit of rationalization—a concept that a reviewer in 2004 called "a Weberian and Progressivist discourse"—would help America to become more efficient and hence able to better distribute wealth, stimulate ethical and spiritual growth, and move toward a "higher motive than mere profit."[23] A cornerstone of Bemis's proposal was to cut costs by moving labor from dirty and messy job sites to efficient factories and clean architectural studios. Many of the costs that Bemis wished to cut would be, in practical terms, wages for contractors and construction crews. Their effort and expertise would be replaced by enhanced (modular) coordination among elites. Work (and workers) could be better controlled in factories, where experts and managers had little use for the experience earned through years on the job site. Rationalization in the building industry, as in so many other industries, meant the objectification and mechanization of labor.[24]

Even so, Bemis believed that rationalization in the building industry, "as may be seen in the history of the introduction of all labor-saving machinery, is inevitable, is a profound irresistible certainty, often held back here and there but nevertheless always advancing." He conceded that such progress had a "tragic" side to the extent that it dislocated business and labor and caused injury and loss, and he warned his readers to prepare for "conflict between the demands of society and those of contractors and labor, and others whose occupations depend upon the older order of things." Although "vested interests" in the industry would be likely to voice "clamorous protests," Bemis predicted that even these champions of the older order of things would, "within a decade, make the necessary readjustments and continue their economic life—and probably with advantage." He remained confident that technological improvement in the industry would silence the clamor and eventually stimulate a virtuous cycle: wages would increase, costs would decrease, and the enhanced "purchasing power" of workers would allow them to afford the new modular homes. Bemis's sweeping vision for the social function of modular coordination distinguishes his ideas from the narrow fixation on prefabrication that his contemporaries and successors pursued.[25]

Modular Coordination, from Theory to Standards to Practice

Tragically, Bemis died in 1936 just as the third volume of *The Evolving House* was being bound for publication. Bemis's colleagues and heirs, moved by his commitment and drawn to the logic of his proposal, developed soon after his death practical applications of his modular theory and the institutional means for its advocacy: the Modular Service Association (an industry trade group) and the Albert Farwell Bemis Foundation (a patron of housing research). In 1938 the association and the foundation cosponsored the establishment of an industry standards committee, organized under the auspices of the American Standards Association, known as A62, Coordination of Dimensions of Building Materials and Equipment. The American Institute of Architects (AIA) and the Producers' Council, a building industry trade association, agreed to coordinate the administrative functions of the committee.[26]

The A62 committee's work slowed during World War II, but by 1945 the American Standards Association had approved the first A62 standard, "Basis for the Coordination of Dimensions of Building Materials and Equipment." The Modular Service Association published a guidebook to accompany the standard the following year—the *A62 Guide for Modular Coordination*, duly dedicated to the memory of Albert Farwell Bemis.[27] By 1948 work in seventeen A62 subcommittees had generated standards for dimensional coordination of masonry, clay and concrete units, and flue linings. Projects still in progress at that point dealt with metal and wood windows, wood doors, glass blocks, and a variety of wall panels and components. In 1957 two additional trade groups—the National Association of Home Builders and the Associated General Contractors of America—joined forces with the AIA and the Producers' Council to form a new group, the Modular Building Standards Association, dedicated to the promotion of A62 standards and the four-inch cubical module.[28]

A62 standards were voluntary standards; in other words, no laws or regulations compelled anyone to use them. Instead, the collaborative process that went into the creation of these standards was designed to convince individual builders and architects of a widespread consensus around the utility of these standards. At the same time as this private movement to encourage voluntary coordination, entities within the state and federal governments took measures to require the use of modular standards. For example, when the US Congress passed the Housing Act of 1957, it included requirements to use modular practice in public housing, low-rent housing, and military housing. One year later, the US

Department of Veterans Affairs revised its rules to require modular practice in the design of all new hospitals under its jurisdiction.[29]

Modular standards also gained momentum internationally in the 1950s and early 1960s. British architects founded the Modular Society in 1953; its proponents, including British prime minister Harold McMillan, imagined modular coordination as "a way of drawing Britain and the rest of Europe closer together."[30] The European Productivity Agency began an assessment of modular coordination in 1954, and the United Nations published reports in 1962 and 1966 that detailed the advantages of modular coordination for housing projects in Asia, Europe, and the Americas. Taken together, these and other promotional materials and reports published by supporters of modular coordination projected a clear sense of their widespread optimism for a modular future.[31]

Within a decade, however, supporters of prefabrication appropriated the term "modular" and stripped it of the meanings that Bemis and the A62 had tried to instill in it. In the 1930s Bemis had called for the standardization of component parts around the four-inch module, but only as a starting point for the fundamental reorganization of the US building industry and American society. By the 1970s, however, "modular housing" had become little more than a synonym—or, even worse, a branding and marketing slogan—for prefabrication that did not necessarily use a four-inch module. Since builders were under no legal obligation to design on an "open system" basis using a standard four-inch cubical module, many sought to capture higher profits by making proprietary, prefabricated, "closed system" buildings.[32]

The German architect Walter Gropius, founder of the Bauhaus school, anticipated the success of prefabrication in 1964 and lamented the missed aesthetic opportunity:

> Genuine variety without monotony could have been attained if we had taken greater interest and influence in the development and design of an ever more comprehensive production of standardized, component building *parts* which could be assembled into a wide diversity of house types. Instead the idea of prefabrication was seized by manufacturing firms who came up with the stifling project of mass producing whole house types instead of component parts only. The resulting monotony further deepened the horror of a nostalgic, sentimental, unguided public of a prefabricated future.[33]

Had he lived into the 1970s and beyond, Gropius's revulsion could only have intensified. Since the mid-1970s, the single term "modular

Figure 4. Aesthetic and economic contrasts between two styles of modular construction. The image on the left was taken by the author near Sanford, North Carolina; the image on the right is the X-Line 001, manufactured by Hive Modular. *Image courtesy of Hive Modular.*

construction" has been used to refer to two vastly different things. For the segments of the housing market primarily concerned with keeping costs low, "modular" refers to an inexpensive, prefabricated house or building where the requirements of a tight budget overshadow aesthetic embellishment. At the higher end of the market, "modular" describes innovative, modern, efficient, and environmentally friendly designs that might appeal to the affluent readers of *Dwell* magazine. The distance between the economic and aesthetic connotations of the two uses of the same term—cheap and efficient in one context, creative and stylish in the other—indicates that discourses of modularity continue to be fluid, undisciplined, and easily reappropriated.

Le Corbusier and *Le Modulor*

A fascinating episode in the history of modular discourse—one that shows a bitter contest to control language—centers around one of the most compelling personalities in twentieth-century architecture, the Swiss modernist Le Corbusier (born Charles-Édouard Jeanneret). In his books *Le Modulor* (1948) and *Modulor 2* (1955), Le Corbusier described his own system of architectural proportion, which he called the "Modulor." Since the 1920s Le Corbusier had been urging architects to adopt the same spirit of rationality and functionality that guided the design of steamships, airplanes, and automobiles, hence his famous polemic "the house is a machine for living in."[34]

Historians of architecture and mathematics have shown that Le Corbusier based his module on some confused and confusing manipulations of the Fibonacci series. In contrast to Bemis, who emphasized that there was "nothing magical" about his choice of four inches as the basis of his module, only that it was a common measure in existing practice, Le Corbusier constructed a more elaborate justification. He boasted that his "Modulor" synthesized the proportions of man (a six-foot Englishman, to be exact) and the rules of Divine Proportion that could be found in nature, mathematics, and the work of architectural masters such as Vitruvius and Leonardo da Vinci. Scholars have tended to read Le Corbusier's work in intellectual terms, in light of his era's "widespread fascination with mathematics as a potential source of universal truths."[35] A close rereading of *Le Modulor* and *Modulor 2*, however, indicates the extent to which Le Corbusier's frustration with the bureaucratic machinery of international standardization also shaped his "Modulor" vision.[36]

In *Le Modulor* and *Modulor 2*, Le Corbusier described how his invention was as much a product of ethereal inspiration as it was a response to professional rejection. He recounted his bitterness—and subsequent motivation—in *Le Modulor*:

> The AFNOR [French Association for Standardization] had been set up under the Occupation as an aid to the reconstruction of the country; industrialists, engineers and architects had banded together to perform the necessary task of standardizing everything pertaining, in particular, to building. Our man [Le Corbusier] was not invited to sit at that table. . . . On the day on which the first standardized construction series of AFNOR were published, our

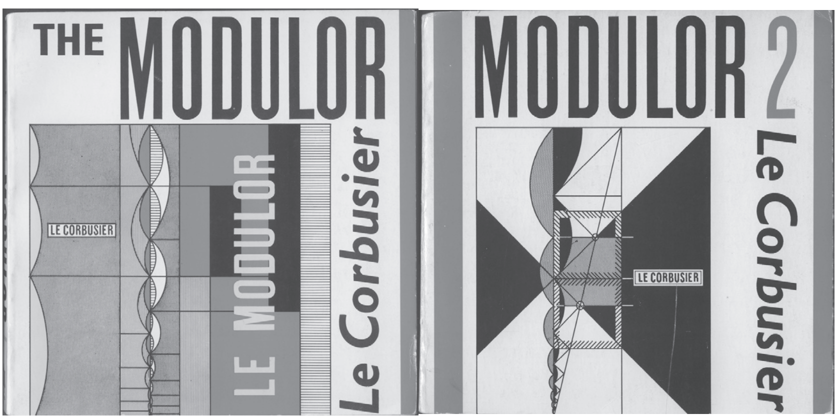

Figure 5. The human dimensions of Le Corbusier's *Modulor.* ©2012 Artists Rights Society (ARS), New York / ADAGP, Paris / F.L.C.

> man decided to set down in concrete form his ideas on the subject of a harmonious measure to the human scale, universally applicable to architecture and mechanics.[37]

By the 1940s Le Corbusier had endured years of ridicule from critics of the International Style of modern architecture, who condemned the stifling, authoritarian, and totalizing implications of a single, arbitrary rule for architecture and construction.[38] When the French decided finally to embrace standardization for the reconstruction of his adopted homeland—over twenty years after Le Corbusier had first advocated a mechanical approach to architectural practice—"our man" was understandably insulted to be marginalized once again.

Le Corbusier returned to this unhappy episode in *Modulor 2* but added a new twist to his complaint: an annoyance with unnamed officials in international standards bodies who were advocating modular coordination. He protested: "Let me add that the promoters of this idea would have aroused more respect if they had not adopted the word 'Modular' as their battle-cry and incorporated it in the name of their organization. The term is, in all fairness, too similar to the Modulor. I have always detested confusion, and ambiguity fills me with distaste."[39]

Le Corbusier complained that the proponents of "modular coordination" were using the term "modular" to mimic his own "Modulor," but chronology tells a different story. He asked his readers to believe that he coined the term "Modulor" after being snubbed by AFNOR in 1943, but in doing so he also claimed implicitly that he knew nothing of Bemis's 1936 book, nothing of the Modular Service Association founded immediately after Bemis's death, and nothing of the A62 committee established in 1938. This seems unlikely. Le Corbusier's network of modernists included Siegfried Giedion and Walter Gropius, who, in turn, worked closely with several promoters of modular coordination, including John Ely Burchard and the two authors of the 1946 *A62 Guide to Modular Coordination*, Myron Adams and Prentice Bradley.[40] It is difficult to believe that the similarities between Bemis's modular and Le Corbusier's Modulor would not have come up in conversations between Burchard—who was vice president at Bemis Industries, Bemis's coauthor for *The Evolving House*, and director of the Bemis Foundation at MIT—and Le Corbusier's close friends and colleagues Giedion and Gropius as well as among the vibrant transatlantic networks of midcentury modern architects. Archival traces of such conversations (or any sort of modular feud) between these leading modern architects are difficult to uncover, but the absence of evidence should not necessarily be interpreted as evidence of absence.[41]

Further, it is difficult to take seriously Le Corbusier's explicit claim of priority. In the introduction to *Modulor 2*, he declared: "There has been no opposition to the Modulor. But a system has appeared, not dimensioned by human stature, whose inventors have chosen a name oddly similar to our designation."[42] In his allusion to the Bemis four-inch module as the "system" that "has appeared," Le Corbusier cast the movement for modular standards more as a nuisance than as opposition or competition. By pointing out that ASA modular standards were "not dimensioned by human stature" (Bemis, as we have seen, based his choice of a four-inch module on existing industry practices), Le Corbusier reminded readers that his system of Modulor measurement was closer to nature and therefore better suited for designing human habitations.

Le Corbusier's Modulor may be seen in some high-profile buildings, including the Unité d'habitation in Marseilles and the Carpenter Center at Harvard University, but it never achieved the same discursive or practical success as the Bemis and A62 four-inch modular standards.[43] Nevertheless, it is Le Corbusier, not Bemis, who features more prominently in histories of housing and architecture in the machine age. Both men are, however, ignored by experts who wield the "power of modularity" in the twenty-first century, even though modular designs for electronic computers clearly drew upon the architectural concepts first developed by Bemis and Le Corbusier.[44]

An Origin Myth: The *Design Rules* of the IBM System/360

There is no record of the precise time, date, or place where professionals working with computers and electronics first recognized the value of the principles of modular construction. It is abundantly clear, however, that modularity rapidly became a powerful means for ordering electronic computer systems during the 1940s, 1950s, and 1960s, an era when computer designers began to rely heavily on architectural metaphors to describe their work.

The most detailed history of modularity in computing can be found in *Design Rules, Volume I: The Power of Modularity* by Harvard Business School professors Carliss Baldwin and Kim Clark. As we will see, their history might more accurately be termed an origin myth. But since origin myths have a certain staying power, and since Baldwin and Clark stand out from their peers in acknowledging that modularity's history is important, their account is an essential contribution toward an interdisciplinary history of modularity.

Baldwin and Clark begin the historical chapters of *Design Rules* with a keen observation: "The concept of modularity must exist as a possibility in the minds of designers before it can appear in the designs of the artifacts themselves."[45] Accordingly, their history starts in what they call the "premodular era" of computer designs from 1944 to 1960, with "simple and primitive" machines such as the ENIAC, the EDVAC, and the EDSAC, as well as a design proposal by John von Neumann and his colleagues at Princeton's Institute for Advanced Study. Although the design of these machines allowed for the substitution of some components (such as vacuum tubes) to facilitate the maintenance of the machine, Baldwin and Clark argue that these designs did not specify the level of interchangeability that would come to characterize fully modular systems.[46]

Near the end of the premodular era, IBM engineers experimented with standardized electronic circuits in the hopes that standardization would facilitate mass production, as it had in so many other industries. In late 1957 a group of IBM engineers in Endicott, New York, created the foundations of what they called the Standard Modular System, a development that Baldwin and Clark tout as one of "the first uses of the terms 'module' and 'modular' that we have been able to track down in the technical literature."[47] It was essential for these circuits to have identical dimensions, elements (transistors, resistors, and capacitors), wiring, and connecting pins so that any "pluggable" circuit could be swapped for any other—a design concept strikingly similar to Bemis's vision of dimensional coordination for components such as masonry, wall panels, doors, and windows that are needed to build a house.[48]

IBM engineers soon integrated the standardized circuit design into a major revamping of their manufacturing and product strategies. In 1960 IBM was producing and selling seven different models of computers that were made in different locations with many incompatible components. Because company-wide redundancies and incompatibilities were costly and inefficient, IBM executives decided to create a new family of computers, the IBM System/360, to rationalize the company's operations and product lines. In *Design Rules*, Baldwin and Clark describe how IBM executives systematically applied modular principles to design fifty pieces of new computer hardware, thousands of new software programs, and a new set of manufacturing facilities. With a choice of interchangeable components, including peripherals (such as storage devices, printers, and terminals) and software, IBM's customers would be able to mix, match, and customize the System/360 to meet their specific information-processing needs.

IBM managers found the modular concept useful not only for its connotations of coordinated design within an overarching system architecture but also—and perhaps most importantly—because the concept helped them coordinate their vast supply of expert labor. Fred Brooks, a manager of the software that IBM developed for the System/360, initially believed that all workers should be aware of all the other work on the project. He soon realized, however, that such transparency was impractical, time-consuming, and distracting. Rather than investing so much time and effort into open communication among workers, the benefits of specialization could be achieved better if workers were "encapsulated" and shielded from the internal details of other components. This strategy—termed "information hiding" by software engineer David Parnas—required that workers only see the interfaces to other components in the system. Managers and executives in the higher reaches of IBM's corporate hierarchy took responsibility for integrating the work of the subgroups into an overall system architecture and product strategies—just as the architects who followed Bemis's modular standards took responsibility from the engineers and construction crews working on job sites.[49]

The IBM System/360, which Baldwin and Clark called the "first modular computer family," was a resounding success. IBM's application of modular principles throughout all aspects of system design, production, management, and labor created a cohesive collection of components that could be adapted to meet the computational needs of many different users. From the standpoint of IBM executives and managers, the modular design of the System/360 streamlined design and manufacturing processes and generated new economies of scale and scope through the reduction of variety and incompatibility. It was, in *Fortune* magazine's famous description, a "$5,000,000,000 gamble" that paid off fabulously.[50] Standardization within the firm led to unprecedented success for IBM in the marketplace: thanks to the high demand for the System/360, IBM's net income doubled between 1965 and 1969, when it hit nearly $2 billion.[51] As a result, the System/360 represented more than a series of compatible components; it became a dominant platform and a new international de facto standard that enabled IBM to reassert its leadership in the global computer industry. "Compatibility" soon became the dominant rhetorical and technological imperative of the computer industry, and the modular concept became a permanent fixture of computer hardware and software design.[52]

Baldwin and Clark's history of modularity at IBM identifies how modular concepts informed the production of the leading computer platform of the 1960s and 1970s. In the process, their history suggests a common theme in the "modular" discourses that emerged in a variety of disciplines between the 1970s and the 2000s. The sudden appearance of modular concepts in the work of neuroscientists, knitters, and economists registered the depth of the computational turn in the late twentieth century. They all employed strategies for ordering information, and they all reflected the pervasiveness of computers as tools, metaphors, and sources of inspiration. If Baldwin and Clark's account is accurate, then we would be justified in concluding that the interdisciplinary appeal of modularity is, at its very core, a side effect of computerization. Computerization, in turn, grew from the efficiency-seeking strategies of IBM managers to streamline and standardize their operations and products.

Tentative support for this conclusion—that an interdisciplinary history of modularity has at its source the IBM management strategies of the early 1960s—may be found in the work of the English poet and experimental artist Dick Higgins. After studying composition in the 1950s with the avant-garde composer and theorist John Cage at the New School for Social Research, Higgins founded Something Else Press in 1963 and published writings by Gertrude Stein, Marshall McLuhan, and members of the network of avant-garde artists and musicians who called themselves Fluxus. Higgins, an active member of the Fluxus collective, coined the term "intermedia" to describe the interdisciplinary, multimodal style of artistic activities that became increasingly prevalent in the mid-1960s. In the early 1970s Higgins showcased his engagement and fascination with the intersection of computers and poetry when he used the IBM programming language FORTRAN IV to randomize the lines in a canto of his aleatory poem *A Book about Love & War & Death.* In 1974, still inspired by the confluence of technology and language, Higgins published a collection simply titled *Modular Poems.*[53]

Although the rapid spread of modular discourse in poetry, education, management, and military strategy further supports the centrality of IBM's design decisions for the subsequent history of modularity, two problems undermine the viability of this causal explanation. The first problem, as we have seen, is that the account in *Design Rules* misses the extensive program of modular coordination (inspired by Bemis's four-inch cubical module and standardized by national and international organizations), which predates IBM's System/360 by over two decades. Computer designers in the 1950s and 1960s did not always account for the sources of the metaphors that they enthusiastically adopted, such as "architecture," "throughput," and "modularity." These metaphors nevertheless provided fertile conceptual ground for the groundbreaking developments in computer hardware and software. When computer engineers recycled notions of modularity, however, they paid little attention to the moralistic, progressive, and humanistic spirit that informed Bemis's vision of rationalization.

The second problem with the history of modularity in *Design Rules* is its omission of earlier uses of modular principles in electronics and computer design. The term "modular" did not, as Baldwin and Clark claim, first appear in the technical literature with IBM's Standard Modular System of 1957–58. In November 1953 an anonymous article appeared in the *National Bureau of Standards Technical News Bulletin* with the title "Project Tinkertoy: Modular Design of Electronics and Mechanized Production of Electronics." The article, probably written by Robert Henry, chief of the Electronics Division in the Process Technology Section at the bureau, described a recently declassified program that had the basic objective of the "development of facilities or systems suitable for rapid mobilization in emergency periods."[54] "Modular Design" referred to the dimensional standardization of components, or "modules"; "Mechanized Production" referred to the application of machine techniques to component production. Engineers at the bureau hoped that this combination would reduce bottlenecks in the procurement process and facilitate rapid scaling-up in the production of electronic components.[55]

The origins of Project Tinkertoy stretch back to World War II, when the US Navy sponsored National Bureau of Standards researchers to study techniques for printed circuits. By 1949 the bureau had completed the "first modular design of military electronic equipment." A precise account of how or when the modular concepts at the heart of Project Tinkertoy "spilled over" to IBM during the 1950s is not available, but it is clear that electronic modules had become a common topic of conversation within the networks of military agencies and their contractors by the late 1950s.[56]

One trading zone for engineers working in the military and government labs and for private contractors was the project to design and build the Semi-Automatic Ground Environment (SAGE) computerized air defense system. A 1956 promotional film for SAGE, produced by IBM's Military Products Division with the aid of the Department of Defense, the US Air Force, and Boeing, described the many difficulties of equipping modern warplanes with electronic computers. The problems of space and weight, reliability, and maintenance, declared the film's narrator, "were all finally solved by employing the basic principle of modular construction." At the very point when the narrator mentions "modular construction," the video footage shifts abruptly: industrial images of airplanes and engineers give way to a calm, domestic scene

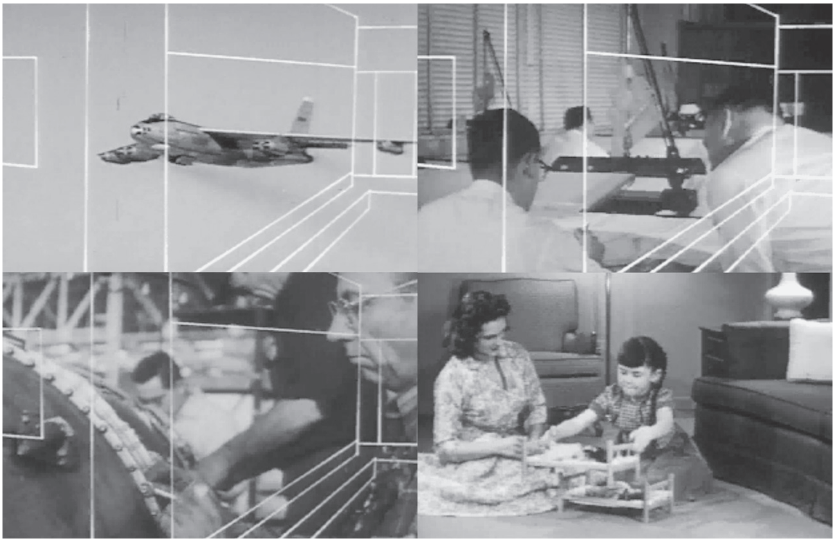

Figure 6. Modular design to the rescue in 1950s American propaganda. Scenes from IBM Corporation, Military Products Division, *On Guard! The Story of SAGE* (1956).

where a mother and her plump-faced, pony-tailed daughter are playing with miniature wooden bunk beds. The narrator, unperturbed by the contrast, continues: “The same multiple arrangement principle which was applied in the design of this doll furniture enabled the Air Force to procure an airborne computer. By designing an electronic assembly in self-contained units, which are then joined, a computer of flexible construction was achieved.”[57]

A second path for the spread of modular concepts, discourse, and machines that predated the IBM System/360 was the “modules” produced by Digital Equipment Corporation in the late 1950s. Cofounders Ken Olsen and Harlan Anderson worked in the MIT Lincoln Lab on the Whirlwind computer, a navy-sponsored project started in 1944 that eventually provided the foundation for the memory technologies used by SAGE. While at MIT, Olsen and Anderson observed high user demand for small, interactive computers. They were able to secure enough funding to found Digital in 1957, consciously avoiding the term “computer” because their sponsors were skeptical that a new computer company could compete with IBM. Digital’s first products were Digital Laboratory Modules, designed to “sit on an engineer’s workbench or be mounted in a scientist’s equipment rack.”[58]

The Digital modules had identical dimensions and a clear function: to encapsulate the circuitry inside the module cases and therefore allow users to interconnect a number of modules through preinstalled plugs, facilitating "the rapid construction of logic systems."[59] Although it is not clear why Olsen and his colleagues decided to feature the term "module" so prominently, there are unmistakable parallels between the Digital designs, the SAGE computers, Project Tinkertoy, and the A62 modular standards that called for dimensional coordination throughout the building industry. Digital's choice of terminology helped distinguish it from IBM; while IBM sold computers, Digital sold only modules. Digital modules quickly became very successful and provided the foundation for Digital's successful PDP family of minicomputers.[60]

While it is clear that the modular designs of Project Tinkertoy, Digital Laboratory Modules, and SAGE predate the System/360, the available evidence makes it difficult to answer several questions that would explain the interdisciplinary spread of modular practice with more precision: Why did Robert Henry and his colleagues at the Bureau of Standards decide to use the term "Tinkertoy" (a children's toy set introduced in 1914) so prominently? Why did Olsen choose the term "module" for his entrepreneurial logic machines? And why did the propagandists who produced the 1956 SAGE promotional film go out of their way to point out the similarities between the air force's airborne computer and the design of a little girl's toy furniture? Even with these questions unanswered, it is impossible to accept Baldwin and Clark's suggestion that modular design rules originated with the efficiency-seeking motivations of IBM's computer and electronics engineers. Long before IBM decided that its System/360 should be modular, the earliest conceptual and practical advances in modular electronics followed from the military sponsorship of a system of production that could be mobilized, at a moment's notice, to defend Americans from what they saw as the imminent threat of thermonuclear war.

Conclusions

Albert Farwell Bemis had a specific goal in mind when he patented and published the details of his four-inch cubical module in the early 1930s: to rationalize, organize, and reform American housing and American shelter. Within a few decades, the context in which Bemis developed his modular concept fell by the wayside as engineers and experts in a wide variety of fields recycled discourses of modularity into strategies of control that they used in numerous cultural, political, technological, and aesthetic contexts. By the turn of the twenty-first century, discourses of modularity had flooded technical professions and disciplines. Economists and business strategists gave advice for managing in the "modular age." Computer scientists developed new applications to fit within the Internet's modular network architecture. Teachers and educational theorists divided complicated subjects into modular lesson plans. Biologists, neuroscientists, and psychiatrists debated the extent to which bodies, brains, and human consciousness could be analyzed as modular systems. Modularity emerged from all of these contexts as a technical, aesthetic, and power-laden concept. In short, for people who needed tools to conceptualize and master complexity, modularity provided an obvious and powerful solution, perhaps even a glimpse of the deep structure of nature itself.

In many respects, the meanings of modularity changed as the term was adopted and adapted by experts who used it to describe industrial, electronic, and natural systems. In the 1930s Bemis intended his four-inch cubical modules to be the conceptual building blocks of a society that could shelter its entire population. The modular pioneers in the networks of American defense contractors in the 1950s and 1960s had a different vision for their society. They, like Bemis, used modular principles to rationalize and order the world by black-boxing technological and organizational problems. But where Bemis longed for social harmony, the cold war modular architects designed modular electronics and computers to strengthen American military capabilities and make a tidy profit along the way. Biologists in the 1980s and 1990s who described the brain as a modular system abandoned the industrial, material, and economic aspects of modular practice; they were more interested in modularity as a conceptual tool that might explain natural phenomena that had thus far eluded human comprehension.

Any account of the spread of modular concepts across disciplinary boundaries is hindered by the relatively few examples where architects, engineers, and other professionals clearly and self-reflectively explained why they preferred the term "modular" to alternative words and concepts. Many authors and experts in the late twentieth century simply began to use the term, leaving few traces of the changes in their cognitive and discursive strategies. Nevertheless, the numerous silences, omissions, and irregularities in the records that document the interdisciplinary spread of modular concepts and ideas do not detract from the significance—indeed, the near-omnipresence—of modular discourse and modular practice in the late twentieth and early twenty-first centuries; instead, they underscore the need for further research that can explain both the idiosyncrasies of modular concepts in various disciplines and the overall coherence and historical significance of modular practices that emerged across diverse professional and disciplinary settings in the late twentieth century.[61]

Historians who investigate human concepts and strategies to organize and use information should not restrict themselves to a single style of inquiry, a specific subset of machines, a particular discipline or profession, or a narrow conception of their audience. If framed in an interdisciplinary way, information history can inform scholarship by intellectual historians and historians of science and technology who trace the circulation of ideas across geographical, temporal, cultural, and political boundaries.[62] Information historians now have the opportunity to show how information is woven intricately throughout human technologies and organizations, to shed light on social interactions that were thought to be black-boxed, and to illuminate the unending struggle of humanity to order its inherently chaotic existence.

Notes

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17. Bemis, *Evolving House: Volume III,* 66–77.

18. Ibid., 88–91.

19. Ibid., 64.

20. The appendix to volume 3 is a lengthy survey, directed by John Ely Burchard, of American prefabrication initiatives that was based on a questionnaire sent to hundreds of American building firms. In 1938 Burchard, a noted architect in national and international circles, became director of the Bemis Foundation at MIT, where he directed several studies of prefabrication. Burchard later became director of the MIT libraries and the first dean of the humanities at MIT. See also Burnham Kelly, *The Prefabrication of Houses: A Study of the Albert Farwell Bemis Foundation on the Prefabrication Industry in the United States* (Cambridge, MA: Technology Press, 1951); Gilbert Herbert, *The Dream of the Factory-Made House: Walter Gropius and Konrad Wachsmann* (Cambridge, MA: MIT Press, 1984); Eric Mumford, *The CIAM Discourse on Urbanism, 1928–1960* (Cambridge, MA: MIT Press, 2000).

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