Apart from the physical role that construction plays in providing technical solutions to problems of insulation, material behavior, and structural integrity, it has an intellectual role to play as a complex, multi-leveled field of concern, a complement to form, space, and function with its own distinct bias. This intellectual aspect constitutes the theory of the field. Theory is an intellectual discipline, an abstract knowledge of the principles of a subject. In construction it cannot, therefore, merely be a collection of solutions or a catalogue of current building practice. It isn’t structural mechanics either, which is a comprehensive method of calculation and dimensioning rather than a theory. What is it then? If we ask what it is that can concern constructors on an intellectual level we find issues like systems theory, morphology, geometry, problems of scale, perception, ethics (that is: so-called «truth», «honesty», or «integrity» and their contradictions), and aesthetics, which is a philosophical discipline, related to logic. A theory that is made up of these elements is entirely dependent on how a constructor thinks, and so we need to define how technological thought works in order to develop a theory of construction.

THE «HARD» AND «SOFT» COMPONENTS OF TECHNOLOGICAL THOUGHT

The special category we call technology is a generic term that denotes a collection of many fields. What they all have in common is that they use a mix of scientific method and empiricism that base on two distinct modes of thinking to make objects that function. Thus technologies incorporate two diametrically opposed views of the world: one hierarchically ordered, and the other, the apparently random pragmatism of technical manufacture. The balance between these two is fluid and can shift suddenly.

Technologists think in ways that differ from other professionals. The physicist and writer C. P. Snow once perceived a cleft between science and humanism, from which he developed his theory of the «two cultures».

1 He considered their differences to be unbridgeable. But the cleft he described is far less drastic than the chasm that exists between these two and technology. As a non-technologist, he was conceptually not sensitized to perceive it. But as builders, we feel this chasm acutely. To some it appears as a hiatus, a basic flaw in our profession, an irreconcilable dichotomy between theory and making, while in others it presents a unique challenge, a drive to create a bridge between them. It is this bridge, this glue between two otherwise incompatible fields that constitutes the uniqueness of technology.

The issue that bonds science and humanism closely together in apposition to technology despite their many differences is their preoccupation with systemic aspects of human knowledge. Scientists and humanists focus on the hierarchical organization of perception, thought, and value, and therefore the
systems they design are always understood to be of a higher order than the elements of which they are composed. Scientists and humanists examine abstractions like concepts, hypotheses, and theories, through which they aim to discover knowledge and gain insight into nature and behavior. Both use analysis although scientists have developed a distinct «scientific method» for thinking using quantitative or «hard» analysis. This thought form is linear and hierarchical in nature and it strives to be «objective» in order to make its paths repeatable to others and thus independent of a thinker’s personal characteristics. For that reason scientists are also interested in the method of thought or epistemology.

Matrix thinking, sometimes called empirical, lateral, associative, or intuitive thinking on the other hand, is a multi-dimensional thought-form that can use clear, linear thought tracks like scientific method, but it can also jump back and forth from one path to another using association, and even from one level or scale of thinking to another, for instance from practical problem-solving to broad historical considerations. How it does this depends solely on each thinker’s personal interests, value system, or cultural background. Since it is to a great extent subjective rather than objective, matrix thinkers are not interested in epistemology, but they use anything that they find to hand in order to solve problems. Matrix thinking is the creative or «soft» side of technology.

THE RELATIONSHIP BETWEEN SYSTEM AND DETAIL

Technological thought is a hybrid of both the hierarchical and the matrix thought modes with special characteristics borrowed from the one or the other of its constituent parts. In technological thought for instance, the system is frequently less interesting than a crucial constituent part, which makes an object work. This means that the relationship between the whole and the part in technological thought is often incremental rather than hierarchical as it is for instance in scientific thinking. So the phrase «only a detail» is meaningless to a technologist. As an example: the electrical automobile is a banal system. But until we can develop one crucial detail: a battery, which is cheap and light, and can store enough energy, the whole thing remains a figment.

We can attribute this non-hierarchical attitude in technology to the goal of technical endeavor, which is the creation of a functioning object and not primarily gaining insight or knowledge like in science and the humanities. Technologists, when they are working as professionals and not reflecting on their field, rely mainly on matrix thought and only concern themselves with systemic aspects when they verify or refine what matrix thinking has led them to develop. Analysis provides them with controllable input in the form of feedback into their next matrix-driven, inventive thought cycle. In order to develop an object, technologists need to be free to adapt and mix portions of mathematical or scientific theory, or any other means, and to modify them in order to make an invention work. The proof of the correctness of a technological method lies in the functioning of the object and not in its adherence to a theory or in the way it fulfills a formal thought process. Scientists and mathematicians have often misunderstood this lack of «intellectual rigor» as «bastardization» of knowledge or sometimes more kindly, but equally condescendingly, as a naïve misunderstanding of theory and thus «applied science».

In reality, however, technology is far more potent a thought form and even dangerous than this superficial evaluation indicates. The danger lies in the failure to consider the implications of technology, and this is a powerful reason for developing a theory of technology and defining its limits and obligations. Those who oppose technological development call it self-referential and deterministic.

The allegation is serious and an indictment of traditional technological curricula. It is certainly true that technologies such as in-vitro-fertilization or concrete construction raise serious ethical or aesthetic issues. The concerns that opponents raise lie in the lack of consideration of their broader implications by technologists, their clients, and society at large. The very fact that such issues are now considered relevant to technology and that this awareness has spread to unrelated fields as diverse as law, finance, and science testifies to the pervasiveness of the matrix component of technological thought in our world. A century ago there was no such awareness in any field. This fact needs to infiltrate the development of academic, technological curricula. Technologists must be made aware of their form of thought in order to include such broader issues in the purview of the field.
These and many other differences between matrix and traditional, hierarchical thought explain the tension that exists between the «hard» and the «soft» modes of thinking in construction, a tension that lies at the heart of all creative thinking. Some thrive on this tension and are energized by it, while others, the more non-creative thinkers, avoid it as painful. It is the tension caused by the combination of these two so different forms that makes technological thinking so vital. The «hard» component analyzes and the «soft» component synthesizes. Together they contribute to making functioning objects.

**TRANSLATION AND TRANSFORMATION, A MATRIX METHOD**

Like the «hard» side encapsulated in scientific method, the «soft» side of technological thought also has its concepts and methods. Until now they have been less studied. I've looked at two of its concepts that I call «translation» and «transformation». The first, translation, moves information between fields and the second: transformation, applies it from one object to another within a field. These two concepts determine how we operate as technologists, and they are directly applicable to both design and construction. The method both translation and transformation use is to shift our standpoint. This shift occurs when a linear thought pattern suddenly jumps from track to track or level to level in matrix thinking. When and where in a thought process this occurs is partly subjective and culture-dependent. The cultural dependency is easiest to demonstrate in the use of language, because different linguistic traditions, which can be professional or cultural, have different concepts and names for objects.

The German language, to take an example from engineering construction, distinguishes between the «Platte», a planar structure that resists out-of-plane forces in bending and the «Scheibe», one that resists in-plane forces in shear (Figure 1, 2). These terms are not identical to the English «flat plate» or «slab», and «shear wall». Whereas the English terms primarily indicate the structure's spatial orientation and its function as a floor or a wall, the German terms do something else. They only define the way the two types of planar structure carry their loads. This explains, for instance, why Robert Maillart had an easier time inventing his remarkable bridges made of planar structures (Figure 3) because he spoke German than he would have had if he had spoken English.

Based on the shifts that engender such differences we can more readily understand how translation and transformation work. In 1830, the foundry master Karl Ludwig Althans built the Sayn Foundry in Bendorf, Germany, a little-known masterpiece of nineteenth-century iron construction (Figure 4). The
multi-leveled complexity of this machine-building is one of its interesting features, but the one I want to stress here is the way Althans used transformation in his structural innovation. If we look at the truss supporting the gantry crane that carried molten iron from the furnace mouth to the casting floor (Figure 5), we see that it rests on a fishbelly truss. The fishbelly truss was only patented about ten years later, so in order to invent it Althans had to draw on other models he knew. The cast I-beam was one, and he used it for the compression chord. Gothic tracery was another, and he used that for transferring shear between the top and bottom chords. But the most remarkable feature, and the one that really demonstrates transformation, is his use of a gigantic, laminated wagon spring made of hand-made crucible steel for the tension chord of his truss. We can only understand the magnitude of Althans’s invention if we remember that the very concept of a truss still lay twenty years in the future.

Another transformation was Althans’s use of cannonballs, one of the foundry’s products, as ball bearings for the swiveling derrick cranes, which rotated around the columns of the casting floor (Figure 6). Again, ball bearings would only be patented in France 27 years later in 1857, so Althans had nothing to build on as a model, and he certainly could not have designed his cranes the way he did if he didn’t have ball bearings.

Althans used translation in the façade and the clerestory of the casting hall (Figure 7). Although the tracery reminds us of Gothic church design more than anything else, we get our clue from the diagonal...
stiffening of his fishbelly truss. Ithiel Town had patented one of the most useful prefabricated and standardized wooden bridge types in the US in 1820. The Town Truss (Figure 8) was made of one cross-section and one type of connection. European engineers were interested in its potential and would soon transform it from wood to iron. But even before they did that, Althans translated it from a bridge into a shear panel, a truss, and a bracing mechanism for his highly stressed, cast-iron foundry hall. The hall had to withstand heavy loads rolling dynamically back and forth and swiveling to and fro on the framework, and so the frame is braced laterally and at the back by the massive masonry walls and the furnace block. However, in the glazed front Althans needed further stiffening. The crisscrossing gothic tracery of the Town Truss served his purpose well. And the small-scale panes of glass he inserted in the open interstices of the truss transformed the truss into a shear membrane, not a «shear wall» but a «Scheibe». Althans did the same for the clerestory.

Figure 6
Elevation of the swiveling derrick crane attached to the columns of the Sayn Foundry using cannon balls as ball bearings, 1830 (drawn by Zarli Sein)

Figure 7
Axonometric drawing of the iron structure of the Sayn Foundry, 1830, showing a Town Truss stiffening the façade and the clerestory, 1830 (drawn by Zarli Sein)

Figure 8
Reconstruction of a Town Truss, the Speed River Bridge in Guelph, Canada, 1992 (photograph Ken Rower)
That truss connects the highly loaded columns of the nave and transfers the load to the furnace block. In yet another transformation, he made the characteristic connection points of the diagonals in Town’s system, into monolithic castings, and shifted the connection to the interface between his panels (Figure 9).

Figure 9
Clerestory trussing of the Sayn Foundry, 1830, showing connections between the panels instead of between the ribs (photograph T. F. Peters)

THE ADVANTAGES OF AMBIGUITY:
THE LIGHT-WOOD FRAME

Shifting standpoint gives rise to ambiguity, and ambiguity is another pragmatic and non-hierarchical concept that characterizes building thought. Practitioners have developed pragmatic as well as conceptual approaches to construction. The pragmatic come from the «soft», synthetical mode of thought, while the conceptual stem from the «hard», analytical mode. Stereotyping is always an exaggeration, but in order to characterize the two approaches culturally I called them the «Anglo-Saxon» and the «Germanic» approaches, simply because each culture assigns particular value to one of them. The anti-conceptual, «Anglo-Saxon» attitude to construction is characterized by pragmatic invention. By adopting this approach we are invariably led to the unanswerable: «Why not?» in response to the query whether or not something is possible, rather than to recognition of the subtleties of cultural rules and intellectual limitations as does the more conceptual approach. In Anglo-Saxon culture, the saying goes, everything that is not expressly forbidden is permitted, whereas in Germanic culture everything not expressly allowed is forbidden. The familiar German question: «darf man das?» in response to an unorthodox technological solution, (is it possible to do? —primarily in the sense of thinkable and only secondarily in the sense of an authorization), is meaningless when translated into English. Who would exercise the social authority in Anglo-Saxon society to censor anything that works?

While in the case of Maillart’s concrete bridges, the linguistic Anglo-Saxon «fuzziness» with respect to planar loadbearing elements inhibited innovation, in the case of the American light-wood frame, conceptual ambiguity displays its advantages in a dynamic development.

According to recent research by Ted Cavanagh, the light-wood frame arose out of the cultural interaction between colonial French and English house-building traditions around 1780 in Missouri. It came to a first level of codification as the «balloon-frame» or «Chicago construction» in Chicago between 1830 and 1850 and to a second one as the «Western platform frame» on the American West Coast a century later in the 1940’s. Today, the frame still dominates American residential construction, which accounts for over 80% of American construction activity.

The light-wood frame is ambivalent in nature and bears little resemblance to a traditional timber frame (Figure 10). It can be regarded structurally either as a panel that is stiffened by ribs or a thin stick frame.

Figure 10
Western platform-frame house under construction in Camp Verde, Arizona, 1982 (photograph T. F. Peters)
made rigid by surfacing. If we regard it as a panel system, certain ground rules involving penetration, interface of elements and connecting apply, and if we regard it as a frame it manifests other boundary conditions. But thanks to the ambivalent nature of the system, a builder can mix the different criteria without concern for conceptual distinctions. This leads to a plurality of possibilities in spatial and formal organization, and that has guaranteed the system’s popularity over two centuries of use.

The nail increases the degree of ambiguity. Because the simple connector is spread evenly throughout the object, it works by virtue of statistics, that is: through quantity, rather than through its quality (Figure 11). The pragmatic contractor’s solution is always to use more nails whenever faced with a complicated connection problem. In other words, the behavior of the individual nail under stress and the quality of its function as a connector is of secondary concern. It is rather the quantity and the pattern of its distribution throughout the object that is important.

Figure 11
The simple nailed connection of a light-wood frame relies on the number of connectors rather than on the quality of each nail (photograph T. F. Peters)

Figure 12
The lashing of a traditional southern Chinese bamboo frame used to be in bamboo strips. Today it is made of plastic tape (photograph T. F. Peters)

This «statistical» characteristic is rare but not unique. We find it in the early North American «proto-trusses» developed for road and railway traffic, and there is a parallel in the bamboo scaffolding of Southern China where lashings replace the nails (Figure 12). The builders of light frames and bridges were unconcerned with the quality of the connection and with the capability of the workman who made it. Instead, they relied on many connections. The bamboo frame had severe typhoon loads to withstand, and this meant paying more attention to connection quality. Nevertheless, it too relies on the large number of connections spread throughout the frame (Figure 13).

The statistical nature of such connections renders this type of structure quasi monolithic. A nailed or lashed frame can transmit forces in any number of unanticipated ways (Figure 14) as long as the basic rules of the panel-cum-frame are respected. There are, of course, limits that cannot be exceeded (Figure 15).
Figure 13
The typical multi-story, traditional southern Chinese bamboo scaffolding can stand up to force-ten typhoon winds (photograph T. F. Peters)

But they are limits of material and structural behavior and manipulating the play between the two differing structural systems can largely circumvent these. The greatest and most surprising advantage of the system, however, is that there is a conceptual quality, namely monolithic behavior that is attained by replacing qualitative with quantitative values. This is why the light-wood frame and perhaps the bamboo scaffold too may have served as model for the modern steel high-rise frame and why the skyscraper originated in North America rather than in Europe.

Light-wood framing fulfills two basic criteria of a so-called «high-tech» system: it is made of industrially prefabricated components and it is not constructed piece by piece on site but merely assembled with a minimum of alteration to the components. The wood members and the steel nails, nail plates, hanger straps, and gussets are all prefabricated in standardized lengths and sizes, but in such a basic way that fine tolerances are rendered irrelevant and quality control is
almost totally obviated. The standardized connections and details are so primitive that the usual norms of industrialized prefabrication: precision and the interchangeability of parts, do not apply.

Viewed in this manner, the characteristics of the light-wood frame make it basically different from traditional European framing systems where the quality of every element and every connection counts. They turn traditional disadvantages into innovative qualities of the system and give rise to a novel building culture that is conceptually different from any that preceded it. The advantage of this type of «Anglo-Saxon» ambiguity over clearly defined, precise and highly conceptualized «Germanic» systems is demonstrated by the 200-year success of the light frame throughout North America.

On another level, it is curious to note that the term «ambiguity» has no precise German translation. «Doppel-» or «Mehrdreutigkeit» literally translates as «two» or «several interpretability» and does not incorporate the strong dose of ambivalence between the possible interpretations associated with the English term. «Ambivalenz», a related term, does exist in German, but as a foreign importation. On the other hand, «Eindeutigkeit», literally «single interpretability», or the mathematical, even stronger «Eineindeutigkeit» («one-directed single interpretability»), translates as «unequivocal», «plain», «clear» and does not convey the predetermination of the German term. The concepts do not quite correspond in the two cultures. Thus they provide for differences in technological thinking, and these differences emerge quite clearly in construction.

CONCLUSION

Over the past century, many scholars have attempted to develop a cohesive theory of technology with only moderate success. Possibly the reason that they were ignored was that most of them were either scientists or philosophers, rarely technologists. Not only is there a need for a technical theory of technology to clarify issues of design and construction method, but each specific discipline and each culture must examine its own specific conditions and its own way of thinking. In construction history we have a young, but growing tradition of insiders examining such issues with a view to incorporating the results of their discoveries into technological curricula and analytical studies in the history of construction. David Billington, Ulrich Pfammatter, and Antoine Picon are among the most prominent, and there are also occasional relevant contributors from outside the field, like Subrata Dasgupta, a computer scientist in Louisiana.

The above thoughts attempt to contribute a few building blocks to a culturally determined theory of construction technology. What I think that such thoughts can do for historians of technology generally and for historians of construction in particular is to demonstrate how wonderfully flexible technological thought is in comparison with other, more codified and rigid forms of thinking, how it varies with cultural viewpoint as well as with professional bias, and how it evolves with other aspects of culture.

NOTES