Technological Thought in Building

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INTRODUCTION

Behind the issue and discussion of both highly "technologized" and simply constructed buildings lies the issue of how the designers and builders of these objects, think. Ever since the popularization of various aspects of technology in American architectural thinking between 1985 and the present,' and aided by the originally British "high-tech" movement in design,' building technology has gradually been moving ever more prominently into the mainstream of our design thinking. What technology is, however, has never been very clearly defined, even in Semper's much-cited "Der Stil,"[3] or especially not by Martin Heidegger. We have no clear idea of what it is that distinguishes the technological from other forms of thought. This paper talks about the two main components that make up technological thinking, and discusses several issues that distinguish technological thought from these components. It also examines differences between engineering and architectural variants of technological thought and begins discussing technology as a design thought-form. The goal is to show that this thought-form is, in its several variations, the basic root of all architectural and engineering design.

Construction represents a significant percentage of many countries' gross domestic product so building is obviously important to our civilization. It is important to our culture too and this paper postulates that it is guided by a special mode of thought.

A HYBRID OF SCIENTIFIC AND MATRIX THOUGHT

Scientists and humanists try to discover knowledge or gain insight into nature. Artists create objects that fulfill non-physical needs and are interested in human reactions to them, and designers, builders and technologists make objects for human use. Technological thought, which is what the author calls the thought-form that this last group employs, appears to be a hybrid form that combines the "matrix" or contextual form of intuitive thinking, which is what artists mainly use, and analytical thought, which lies a the heart of scientific thinking.[4] Matrix thinking is a multidimensional thought form. Like scientific or analytical thinking generally, it can follow linear paths made up of logical sequences bedded in a context of parallel, converging or diverging tracks. But it can also make associative "leaps" from one linear track to another or from one level of thinking to another. This gives matrix thinking a personalized character, since the path a thought process takes depends on the thinker's proclivities and priorities and is thus not at all independent of the individual's intellectual and associative makeup. Because of its unstable flexibility, this form of thinking is so powerful and adaptable that it has strongly influenced the scientific and humanist forms that represented the dominant models in the beginning to the middle of the last century.

While technologists are interested in objects, analytical thinkers deal with abstractions, that is: concepts, hypotheses and theories. Scientists, the most constrained type of analytical thinker, are now very much influenced by matrix thought, but their method of examination remains chiefly analytical and well within the limits of the hierarchical system of scientific method. Technologists, who are "makers" often do that too, especially when they need to control and confirm quantifiable parts of their designs, but they do more, not as an adjunct to their method, but as an integral component of it. Construction, building processes and design are linked, and builders use criteria based on their personal and cultural values in addition to analysis to help define relationships between design elements and processes. In contrast to scientific method, however, a technological method's correctness lies solely in the functioning of the object, not in its logic. So builders are rarely concerned with epistemology, the method of knowledge. This explains why unschooled inventors continually try and invent the *perpetuum mobile* in spite of its proven impossibility. Science, they argue uninformedly, has been proven wrong before, and there is no reason why it will not be proven wrong again. This can certainly be true when the parameters of a problem vary,[5] but not, of course within a given set of parameters.

Scientific method, as distinct from the thought processes that scientists use to generate or speculate on their problems, stays within clearly delineated boundaries and is so constructed that it is independent of the thinker's personal or even cultural value system. It uses processes that anyone can replicate to provide unambiguous answers to questions. Builders need this form of thinking to analyze certain quantifiable aspects of their designs and help control the process of design synthesis. In the course of building the Eddystone Lighthouse off the southern coast of England in 1756, John Smeaton introduced scientific method to design by using it to analyze and understand how hydraulic cement worked chemically.[6] But, as opposed to the nascent field of materials science as represented by researchers like Charles Pasley and Thomas Tredgold in England, or Louis-Joseph Vicat and Clément-Louis Treussart in France,' or to the creators of analytical engineering theory like Johann Eytelwein in Prussia, Franz Joseph von Gerstner in Austria, C. M. L. Henri Navier in France or Eaton Hodgkinson in England,[8] Smeaton's goal was technological rather than scientific; he wanted to build a better object and not merely provide new insight into the nature of cement. Seventy years later Navier formally incorporated scientific method in building when he developed analytical structural models that were independent of scale and material and codified analytical statics, making it useful for builders. His definition of live-loading on bridges for instance as a unit of 200 kg/m^2 instead of the previously used, site-specific, expected load on a bridge allowed engineers to compare different spans and loading conditions objectively and thus scientifically, and to abstract quantifiable characteristics that they could then apply to a range of specific cases.[9] In this way scientific thinking helped builders understand technological behavior but it could not help them design. It is a useful tool to analyze and optimize design aspects of an object once it has been made, but not to create it.

Therefore builders, creative architects, engineers and others need associative thinking, the other half of technological thought to create structures or processes. Only those who practice this hybrid mode of thought that balances between associative synthesis and analysis realize that *homo sapiens* is and *homo faber* are one and the same in technology. Those, like many engineering researchers or many artists too, who practice solely either analytical or synthetical thinking see the other form as a distraction to their own "pure" mode of thought. Because of the continual balancing act that the relationship between the analytical and the synthetical sides of this thought form demands, technological thought has to be more flexible than either of its components. Since science and design follow such different goals, they coexist in an uneasy relationship in technology that can be characterized as an unstable intellectual equilibrium or a dialectic that works to create useful solutions. Calatrava's work more than that of any other modern builder, makes this unstable equilibrium visible, even more than that of Renzo Piano, Peter Rice, or Jorg Schlaich in their skeletal or gossamer roof structures. Sigfried Giedion's interest in transformable furniture reflects this inherent ambivalence in technology in the mid-nineteenth century," and more recently Antoine Picon has discussed this ambivalence from another standpoint as a preoccupation with "movement.""

Until recently, it has been the analytical and quantifiable, or "hard" aspect of technology that has received more attention in our culture, while non-quantifiable aspects have been derided as "soft." But builders are "makers," and therefore they use this comprehensive or "soft" form of technology that is concerned with creating objects, not simply analyzing them mathematically. Softtechnology parallels matrix thinking, since it includes both quantifiable, (and therefore "hard" or repeatable), as well as non-quantifiable or "personal" types of thinking. Soft technological thinking balances between *theories* of form and perception, the analytical *methods* of science and mathematics, and the practical *processes* of dealing with humans and materials. It thus crosses the boundaries between the ideal and the pragmatic in many ways. Soft technology is inclusive, and it has several aspects that are "qualifiable," not quantifiable. They are issues of scale, system, and procedural thinking.

SCALE

One of the chief differences between the "hard" and the "soft" components of technological thought lies in their divergent concept of scale. This is even reflected in different uses of vocabulary. A "detail" to an analyst is a "hierarchically minor and subordinate part" of a system, while to a designer it is a "small-scale problem." The difference is often the reason for structural failure. The "O-ring" gaskets that failed on the space shuttle Challenger in 1986 for instance were a vital small-scale problem, not a minor part. The NASA engineers knew that the rings were faulty and tried to warn the project managers, who, because they were principally not technologically trained, failed to understand that the "small part" that was worrying the constructors was not intrinsically "minor" but in reality "crucial." Sculptors and architects intuitively know that a change in scale alters all proportions and all relationships between parts, and ever since Galileo Galilei,[12] engineers have developed "model laws" that define such relationships mathematically in terms of structural behavior. Joseph-Louis Vicat, the concrete pioneer, inadvertently crossed the boundary of what scientific analysis can do for building in 1831 because he neglected the all-important issue of scale. He was an engineer, but when he studied the rust-reducing characteristics of cement, he treated the problem exclusively analytically and did not focus on making a functioning object like a technologist would. Vicat imbedded wires in mortar and found that the mortar inhibited rusting under laboratory conditions. He therefore recommended grouting suspension bridge cables directly into their foundations.[13] But in practice large cables vibrate and loosen their bond with the surrounding grout, and in consequence they rust and fail. Vicat had neglected to test his laboratory model at full scale under field conditions. This distinction between scientific experiment and technological practice was reflected in the intellectual bias of theindustrially oriented Ecole centrale des arts et manufactures founded in Paris in 1829 in reaction to the drift of the Ecole polytechnique toward abstract, scientific thinking.[14] One graduate of the Ecole centrale, Gustave Eiffel, successfully developed a component assembly system for his bridges and the tower that hinged on issues of scale. Another, William Jenney, was centrally involved in the development of the tall-building frame.

SYSTEM CONCEPT

Like "detail," the word "system" also means different things to the analyst and the builder. It builds on the understanding of the role that scale plays in structure and form. To both it is the principle that governs relationships between parts and the whole, but the scientist understands it as the hierarchical organizing principle that distinguishes the primary from the subordinate while the designer-builder usually understands it as a non-hierarchical kit-of-parts. Even the earliest nineteenth-century iron bridge builders did not design solely hierarchically from the whole to the part, but developed standardized sets of members and connections while they conceived the overall form. They used a dialectic approach, balancing between different scales in their design process. This made the detail as important to them as the whole and changed both their thinking and consequently their use of language. Their dialectic design method reflected the unstable equilibrium that exists in their technological mode of thinking, and that modern designers like Norman Foster or Calatrava have tried to express in visual form. It followed that their intellectual as well as structural preoccupation with equilibrium led nineteenth-century builders to understand design, manufacture, and assembly as dynamic processes. Giedion's and Picon's analyses reflect this technological concern. This form of system thinking standardized relationships between members in nineteenth-century construction, gave rise to economical, repetitive component manufacture, and introduced concepts like monolithic structural behavior or structural redundancy. Eiffel's construction system, a design-matrix of structural constants and variables, carried the idea of building system to maturity at the end of the nineteenth century. His simple and yet sophisticated catalog of wrought-iron parts, connection rules, and erection sequences for the Garabit Bridge (1884)[15] and his tower (1889)[16] paved the way for modern steel-bridge and high-rise construction. It also spilled over into instructional toys like "Erector Set," "Lincoln Logs," or "Lego" as their reflection in our general culture.

PROCEDURAL THINKING

Builders need intellectual strategies to support their system approach to design. The associative quality of matrix thinking leads them to *transforni* or to *translate* information from one format to another. Transformation remolds information within the boundaries of a field while translation crosses borders and moves it from one field to another. Both forms are characteristic of the associative aspect of matrix thinking since they rely on non-predictable, and therefore seemingly illogical "leaps" in thought processes. Transformation and translation are aspects of the concept of "creative misunderstanding".[17]

There are many examples of both in building. When he built the Sayn Foundry in Bendorf near Koblenz (1830-1845), the Prussian ironfounder Karl Ludwig Althans transformed gigantic steel wagon springs into the tension chords of fishbelly trusses and cannonballs into ballbearings on his swiveling derrick cranes.[18] The engineer Marc Brunel observed how the pipeworm or *terredo navalis* drilled through ship timbers and translated the process into the first mechanical tunneling shield for the Thames Tunnel (1824-1843). Cultural border-crossing can evidently foster the translation process too. While working on Robert Stephenson's Victoria Bridge over the St. Lawrence River in Montreal (1854-1859), the British mechanics who had emigrated to North America seemed able to build more reliable machinery than those who had stayed home.[19]

DIVIDE AND CONQUER

Another common strategy in procedural thought demonstrates a combination of the analytical and synthetical aspects of technological thinking, and shows how the combination of the two is more than the sum of the parts. The strategy consists in dividing problems with conflicting requirements into their constituent parts, solving the components serially, and then reuniting the results into an overall solution. Richard Turner's structure for the Palm House in Kew Gardens (1848) is a rigid frame than can expand and contract with temperature changes. In order to solve the then novel problem with its conflicting requirements of stiffness and flexibility Turner separated the purlins that connected the structural bents from those that carried the glazing panels and the ones that stabilized the mullions, and formed flexible joints between them.[20] When a bottleneck threatened to disrupt the assembly of the London Crystal Palace in 1850, the contractor Charles Fox accelerated the process by decoupling the linear erection sequence from the modular structural geometry. While building the Conway and Britannia Bridges (1846-1850), Robert Stephenson and William Fairbairn saved time by using a primitive form of critical-path method to decouple and then coordinate the experimentation, design and erection phases in parallel. Strategy and tactics derived from military thinking provided builders with further tools to solve problems with continually shifting, interlinked parameters and unanticipated occurrences like the ones that characterized John F. Stevens's reorganization of the Panama Railroad. George W. Goethals used the newly flexible railway system as the backbone of his building process for the Panama Canal, the largest and most complex construction project ever attempted to that date (1904-1914).

CONCLUSION

Technological thought, as it has been defined here, developed over the past two centuries. It is characterized by its hybrid, dialectic and fluctuating nature. It crosses borders, borrows freely and "creatively misunderstands" or translates and transforms methods and strategies taken from other forms of thinking. Its inventiveness and flexibility make it adaptable to many situations and, as a result, it has gradually influenced most other forms of thinking. Today, scientists, artists, economists, businessmen, and even humanists have adopted aspects of technological thinking and this is what makes it the premier thought form of our age, intimately connected to the creation and development of new concepts.

NOTES

[1] primarily by Edward Allen, Kenneth Frampton, Marco Frascari, Peter McCleary, and Tom F. Peters.

[2] begun by the "Archigram" group in the 1960's and the Japanese "Metabolists" and more recently by Norman Foster and others in Britain, as well as Renzo Piano and Santiago Calatrava in France

[3] Gottfried Semper, *Der Stil in den technischen und tektonischen Kiinsten, oderpraktische Aesthetik: ein Handbuch für Techniker, Kiinstler und Kunstfreunde.* 2 vols. (Frankfurt a.M.: Verlag für Kunst und Wissenschaft, 1860 / Munich: F. Brugmann, 1863).

[4] The term "matrix" is preferable to Edward de Bono's "lateral" because it describes intuitive thought's multi-dimensionality in contrast to "vertical" thought's linear nature. See his *The use of lateral thinking.* (London: Cape, 1967).

[5] Tom F. Peters, *Building the nineteenth century* (Cambridge MA: MIT, 1996), Mont Cenis Tunnel, pp. 136-141.

[6] John Smeaton, *A narrative of the building and a description of the construction of the Edystone Lighthouse with stone...* (London: G. Nichol, 1791), pp. 102-123, Part 3, Chapter 4 "Containing EXPERIMENTS to ascertain a compleat Composition for WATER-CEMENTS, with their Results". However, Smeaton did not always apply chemical analysis in his experiments as his observations on a "reddish, or brownish stone" he later tried demonstrate (p.118).

[7] See: Charles William Pasley, *Observations on limes, calcareous cements, mortars, stucco and concrete, and on puzzolanas, naturalandartificial.* (London: Weale, 1838); Thomas Tredgold, *Practical Essay on the Strength of Cast Iron, intended for the assistance of engineers...* (London: J. Taylor, 1822); Louis-Joseph Vicat, *Recherches expérimentales sur les chaw de construction, les bétons et les mortiers ordinaires.* (Paris: Goujon, 1818); Clément-Louis Treussart, *Mémoire sur les mortiers hydrauliques et ordinaires.* (Paris: Carilian-Goeury, 1829)

[8] Johann Albert Eytelwein, *Handbuch der Mechanik fester Korper und der Hydraulik: rnit vorziiglicher Rücksicht auf ihre Anwendung in der Architektrir...* (Berlin: F. T. Lagarde, 1801); Frank Joseph von Gerstner, *Handbuch der Mechanik.* 3 vols. (Prague; Johann Spurny 1832 & 1833 / Vienna: J. P. Sollinger, 1831); Claude Louis Marie Henri Navier, *Rapport à M. Becquey... et Mémoire sur les ponts suspendus.* (Paris: Imprimerie royale/Carilian-Goeury, 1823); and: *Résumé des leçons...* (Paris: Firmin Didot, 1826), 2nd. expanded, 2 vol. ed., (Paris: Carilian-Goeury, 1833-1838).

[9] Tom F. Peters, *Transitions in Engineering.* (Basel: Birkhauser, 1987), pp. 52-53, & 111-112.

[10] Sigfried Giedion, *Mechanization takes command., a contribution to ananymous history.* (New York: Oxford, 1948). Especially in part 5: "Mechanization encounters human surroundings", but also in the rest of the book, as chapter titles such as "Mechanization and death: meat" suggest. Giedion was himself a border-crosser between mechanical engineering, his first profession, and art history, which was his chosen professional field.

[11] Picon, Antoine, "Toward a History of Technological Thought," *Technological Systems and Technological Thought,* Robert Fox ed., (Amsterdam: OPA, 1995).

[12] Galileo Galilei, *Discorsi e dimostrazioni mathematiche, intorno a due nuove scienze...* (Leyden: Elsevier, 1638), p. 129 where Galileo compares bones of a giant and a normal human.

[13] *Annales des ponts et chaussées*, 1ère partie, vol. 1, "Ponts suspendus en fil de fer sur le Rhône", 1831, Paris, p. 119, and footnote 12.

[14] Ulrich Pfammatter, *Die Erfindung des modernen Architekten. Ursprung und Entwicklung seiner wissenschaftlich-industriellen Ausbildung.* (Basel: Birkhauser, 1997).

[15] Gustave Eiffel, *Mémoire sur le viaduc de Garabit, Description, calculs de résistance, montage, epreuves et renseignements diverspar G. Eiffel, Président de la Société des ingénieurs civils* (Paris/Liège: Librairie Polytechnique, Baudry et Cie., 1889), 2 vols.

[16] Gustave Eiffel, *La tour de trois cents mètres* (Paris: Lemercier, 1900), 2 vols.

[17] This term was coined by William J. J. Gordon in his book *Synectics: The Development of Creative Capacity* (New York: Harper, 1961/1991), and used by George M. Prince in *The Practice of Creativity: A Manual for Dynamic Group Problem Solving* (New York: Harper & Row, 1970), and Harold Bloom in *A Map of Misreading* (New York: Oxford, 1975).

[18] Paul-Georg Custodis, "Die Sayner Hhtte in Bendorf," Cologne: *Rheinische Kunststätten,* (# 241, 1980); Tom F. Peters, *Building the nineteenth Century,* op. cit., pp. 211-218.

[19] Arthur Helps, *Life and Labours of Mr. Brassey 1805-1870* (London: Bell and Daldy, 1872), pp. 206-207.

[20] For details of this and the following examples, see: Peters, *Building the nineteenth century,* op. cit.