MATTER

MATERIAL PROCESSES IN ARCHITECTURAL PRODUCTION

EDITED BY
GAIL PETER BORDEN
AND MICHAEL MEREDITH

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Determinacy/indeterminacy

Figure 10.1 *The Forge,* Joseph Wright

From Garrard to Turner, the path is very simple. It is the same path that runs from Lagrange to Carnot, from simple machines to steam engines, from mechanics to thermodynamics – by way of the Industrial Revolution. Wind and water were tamed in diagrams. One simply needed to know geometry or to know how to draw. Matter was dominated by form. With fire, everything changes, even water and wind. Look at *The Forge*, painted by Joseph Wright in 1772 [Figure 10.1]. Water, the paddlewheel, the hammer, weights, strictly and geometrically drawn, still triumph over the ingot in fusion. But the time approaches when victory changes camps. Turner no longer looks from the outside; he enters into Wright's ingot, he enters into the boiler, the furnace, the firebox. He sees matter transformed by fire. This is the new matter of the world at work, where geometry is limited. Everything is overturned. Matter and color triumph over line, geometry, and form.[1]

> Magnesium oxide, a white powder-like substance commonly used as anti-acids, embodies a simple face-centered cubic crystalline structure resulting in a beautiful rectilinear form observed in a molecular level. I have once witnessed a perfect MgO crystal degrade and disappear in real time battered in a beam of electrons. It was in the Spring of 1989, first day of the basic training in electron microscopy. A spartan metal microscope I was introduced to was the first practical and versatile hi-voltage transmission microscope custom built for Kyoto University Institute for Chemical Research by Shimadzu Seisakusho Ltd. in 1962.[2]

Devoid of any extraneous optical accessories and video enhancements, refracted electron beam through the matter is magnified and projected directly on to a fluorescent screen as shade and shadow to be observed. This is as direct and unfiltered observation experience as one can possibly expect. The irony is, the agent allowing one to observe the matter is simultaneously destroying it from being observed. I turn the dial to focus. As soon as the rectilinear shape of the MgO crystal appears on the screen, it begins to fade and dissolve completely within a mere few seconds. This is the precise moment in which I have realized the complex nature of the physical reality. That the world consisting of matter we observe daily is not stationary. It is profoundly temporal, renuous and imperfect so that an action as basic as observing will change the state of the matter irreversibly:

> It is true classically that if we knew the position and the velocity of every particle in the world, or in a box of gas, we could predict exactly what would happen. And therefore the classical world is deterministic.[3]

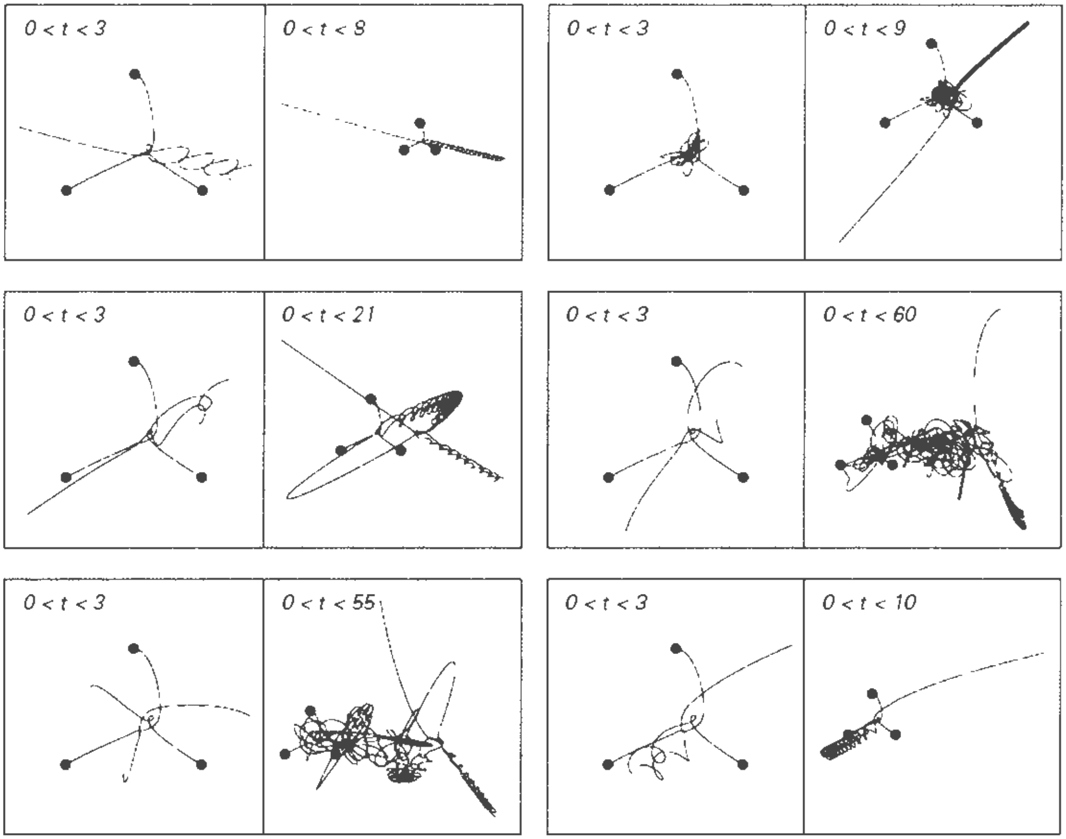


Figure 10.2a–f Initial sequence of three body interaction

Classical mechanics are known to be a simple and beautiful way to describe the relative motion of macroscopic objects. In principle, any problem in mechanics can be solved based on Newton's second Law of Motion. This is indeed true when dealing with one or two bodies in motion. However, it becomes exponentially difficult when the number of bodies involved is greater than two. The famous three-body problem, two planet bodies rotating around a sun, for example, challenged the power of human analysis for ages (Figure 10.2).[4] Such problems cannot be solved in elegant, analytical mathematics with the deterministic accuracy. It is necessary to resort in approximations through heavy numerical calculations.

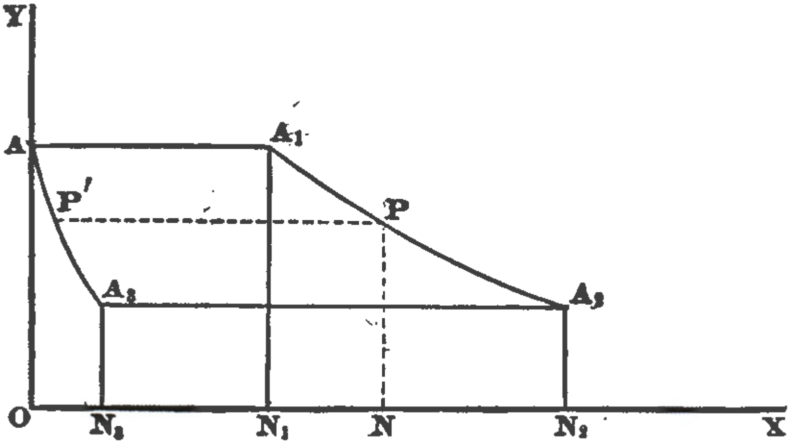
One of many Joseph-Louis Lagrange's contributions to the field of physics was resolving the three-body problem for a special simplified condition based on the hypothesis: The trajectory of an object is determined by finding a path that minimizes the action over time. The significance of this assumption is that it allowed the physical motion of an object tracked in time in Newton mechanics to be treated as a field, a topographic condition over time through the emerging concept of "energy" and a new mathematical tool, "calculus of variations." Trajectory is implicated as field of potentials, no longer described in a strict form of discrete geometry. Newton mechanics is now reduced to a solution of variable calculus under particular conditions, in Lagrangian mechanics. The results just happened to be geometric. From this perspective, Lagrange was already beyond "simple machines" and "geometry" in the territory of the pre-Impressionist painters such as Turner (Figure 10.3):

> Everyone knows that heat can produce motion. That it possesses vast motive-power no one can doubt, in these days when the steam-engine is everywhere so well known ... Nature, in providing us with combustibles on all sides, has given us with the power to produce, at all times and in all places, heat and impelling power which is the result of it. To develop this power, appropriate to our uses, is the object of heat-engines.[5]

Figure 10.3
The Burning of the Houses of Parliament,
Joseph Mallord William Turner

On the other hand, contrary to Serres' remarks, Nicolas Léonard Sadi Carnot may still be well within the Newtonian mode of deterministic thinking. He is often noted as the father of thermal dynamics due to his pioneering work on the relationship among temperature (heat), work (motive-power) and matter in an idealized form of steam engine, the Carnot cycle.[6] The implication: the interchangeability of thermal energy and kinetic energy (first law of thermal dynamics) and reversibility/irreversibility (second law of thermal dynamics – introduction of entropy) were major factors in triggering the fundamental paradigm shift in the world of physics. However, he was very much concerned with quantifying the efficiency of the steam engine in exactitude using standard analytical tools of its time parallel to Garrard's and Wright's paintings (Figures 10.1 and 10.4).

Figure 10.4 The Carnot cycle



In order to truly appreciate the radical departure, the spatial and material nature depicted in Turner's painting, we must look at the works of Maxwell and Boltzmann. As discussed earlier, classical physics dealing with more than three bodies in motion already posed an insurmountable obstacle to the nineteenth-century scientists. Thus, dealing with a molecular level description of the behavior of gas, the task of numerical calculation for every single molecule was technically impossible without massive computational power at their disposal. Instead, they discovered an ingenious work-around in the form of "probability," giving birth to statistical mechanics. The Maxwell–Boltzmann distribution describes the probability distribution of gas molecules' speed in relation to the temperature of the system. Through the introduction of statistics, the individual motion of particles described in classical mechanics can now be treated as an aggregate behavior of molecules over time. The development finally bridges the conceptual gap between Newton mechanics and thermal dynamics, paving the way to the development of quantum mechanics by such giants as Einstein, Heisenberg and Bohr in the early twentieth century. The equation, $S = k \log W$, carved into Boltzman's tombstone, describing the logarithmic relationship between Entropy (S) and Probability (W), the number of possible micro-states corresponding to the macroscopic state of a system, says it all. It demarcates the clear departure from the deterministic thinking in classical mechanics to accepting indeterminacy as part of the fact in nature.

Complexity/precision/extension

> The properties of shear-tie are fully embedded within the solid representation. Any dimension can be derived completely and accurately from the solid model, rendering the once necessary dimensional drawings now obsolete.[7]

The shear-tie mentioned above fastens the exterior skin to the frame of a Boeing 777. In the book *Refabricating Architecture*, Kieran and Timberlake discuss how every component of this airplane is precisely modeled in the virtual environment. In addition to the full description of geometric information, each virtual part is embedded with other design controlling factors such as the physical properties and its lifecycle records. A Boeing 777 consists of over one million parts, an object the size of a small building with enormous complexity. Kieran and Timberlake argue that without the technology to predetermine the data in pinpoint accuracy beyond the simple dimensional tolerances, it would not be economically feasible to build such a complex object. They make a convincing case for architecture and construction industries to adopt the technology already fully embraced in automobile and aerospace industries.

Frank Gehry was one of the earliest to do so. In the Foreword to the book *Iron: Erecting the Walt Disney Concert Hall*, Gehry writes:

> CATIA also allowed extremely complicated steel to go together on the site without the kind of problems that happen on similar sized buildings. Due to the consistency of information and the precision of the calculations, every element tied back to an origin. When an Ironworker was on the scaffolding, he could get someone to survey him a point and know he was within an eighth of an inch.[8]

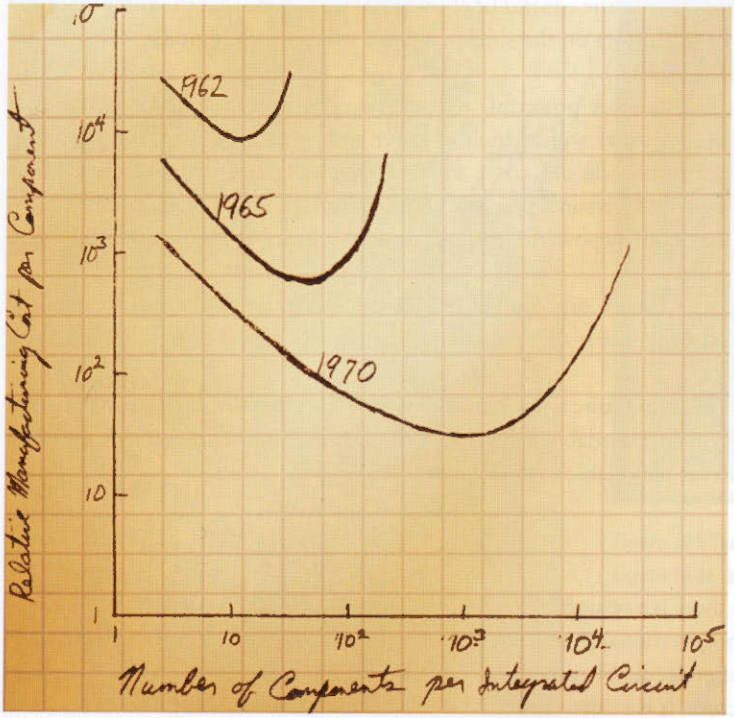


Figure 10.5 Cost vs. component – Moore's original graph

For Gehry, it was an absolute necessity to adopt the technology in order to realize his complex sculptural forms. He goes on to speculate that if it was not for CATIA, the three-dimensional surface modeling program developed for the aerospace industry, it would have taken him decades to meet the computational requirements alone for the design of the Walt Disney Concert Hall.

A building system is literally and metaphorically an extension of a vast number of similar elements. In general, the more complex the building, the more accuracy is expected in extending the elements both in design and in execution to make them economically feasible. The construction of an exceedingly complex building such as the Walt Disney Concert Hall is testament to the recent technological advances in the field, namely the precision and the speed made possible by the new digital tools. If the future of architecture is dependent upon these new digital tools, what makes these tools possible?

Computational muscles

> The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000. I believe that such a large circuit can be built on a single wafer.[9]

In 1965, Gordon Moore, the future co-founder of Intel Corporation, published the now famous article, "Cramming more components onto integrated circuits," in an obscure electronic trade magazine, *Electronics*. He predicted that the number of transistors economically placed on an integrated circuit would increase exponentially, doubling approximately every two years as mentioned in the above quote. This notion has since been widely embraced by the industry as "Moore's Law." The key in reading the article is his careful attention to the impact of such rapid technological advance in the context of economy. If we assume that the computational power is proportional to the number of transistors on the single chip, we will see exponential growth in the power for the same price year by year (Figure 10.5).

Gordon writes, "Computers will be more powerful, and will be organized in completely different ways. Machines similar to those in existence today will be built at lower costs and with faster turn-around." Many future products he mentioned in the article did come to fruition – electronic wristwatches, home computers, automatic controls for automohiles, personal portable communications equipment, to name but a few. The availability of the ubiquitous, increasingly powerful computing and its effect on the way of life seem to echo the technological optimism of the era.

Patrick P. Gelsinger, the current Intel Corp. Senior President, confirmed that the performance/dollar ratio of computers has increased by a factor of over one million in the past 30 years, in line with Moore's Law.[10]

We are surrounded by computers. Our future advancement seems to rely ever more on the continuation of this trend, the exponential increase of the affordable compurational muscles. This is precisely what makes these new digital tools possible and increasingly viable in the field of architecture.

Tumbling Units

In the field of computational physics, there is a resurgent interest in resolving previously unattainable classical mechanics problems through sheer computational power. We are now tantalizingly close to predicting exactly what would happen in the box of gas, molecule by molecule. The affordability of the computational muscles has also impacted the field of architecture. It is evident from the overwhelming trend in the profession as well as in education. However, has the digital revolution really contributed to a significant shift in the way we think and produce building systems, analogous to the way the Industrial Revolution triggered a paradigm shift in the world of physics and ultimately changed the way we see the world?

The current technological obsession in architecture is rather simplistic. As is evident in Gehry's earlier remarks, the advances are measured in terms of speed, accuracy and, in turn, economy. With the deterministic precision made possible by inexpensive computational power, we can design and build a complex building cheaper in a much shorter time. Kieran and Timberlake merely reaffirm this point through the idea of prefabrication and mass customization. I often wonder what would have happened if the massive computational power we have now had been available to the nineteenth-century scientists. Would it have facilitated the paradigm shift? Or would it have hindered the game-altering development in thermal dynamics and statistical mechanics since they did not have to confront the kind of resistance they had to contend with?

My work approaches this question from the opposite end. How can we introduce an architecrural idea equivalent to "probability" in nineteenth-century science? Can we conceive a building method that does not rely on precision in an ordinary sense? Is it possible to form a building system with an indeterminate system? What will be the tectonic implications (Figures 10.6–10.7)?

Tumbling Units were conceived in an attempt to address these questions. The friction-bound ceramic structural units were designed and fabricated as a possible building system with indeterminate internal extensions.

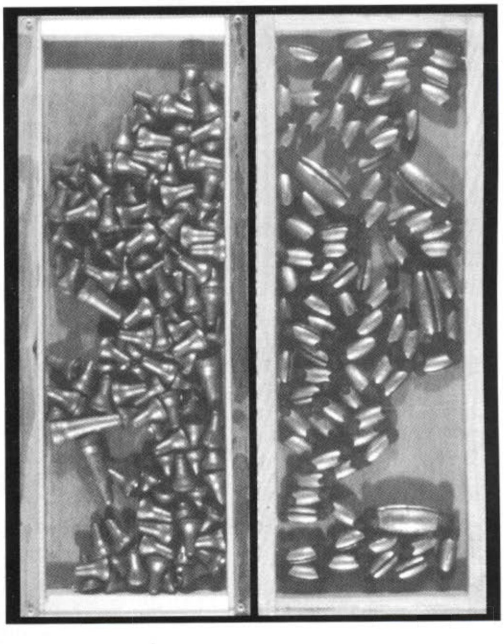


Figure 10.6 Tangling tree branches
Figure 10.7a–b Lead fishing weights under gravity

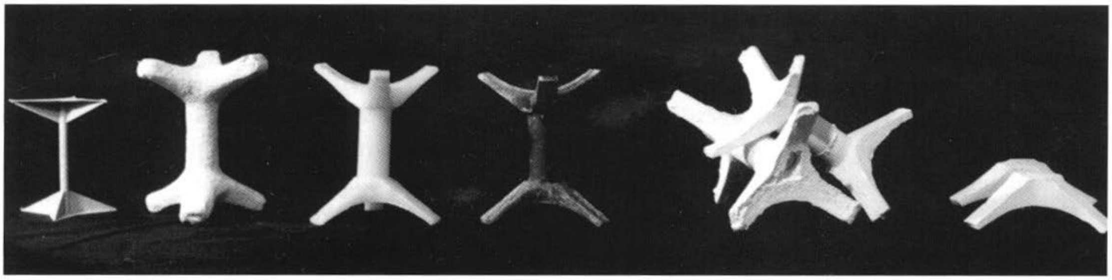


Figure 10.8 Various fabrication attempts of the positive mold and the result of the hydro-cal casts

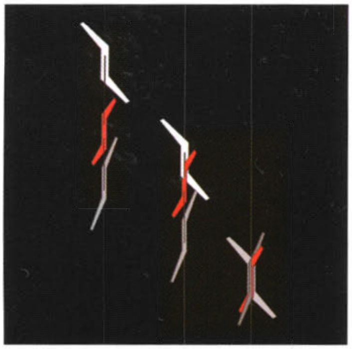
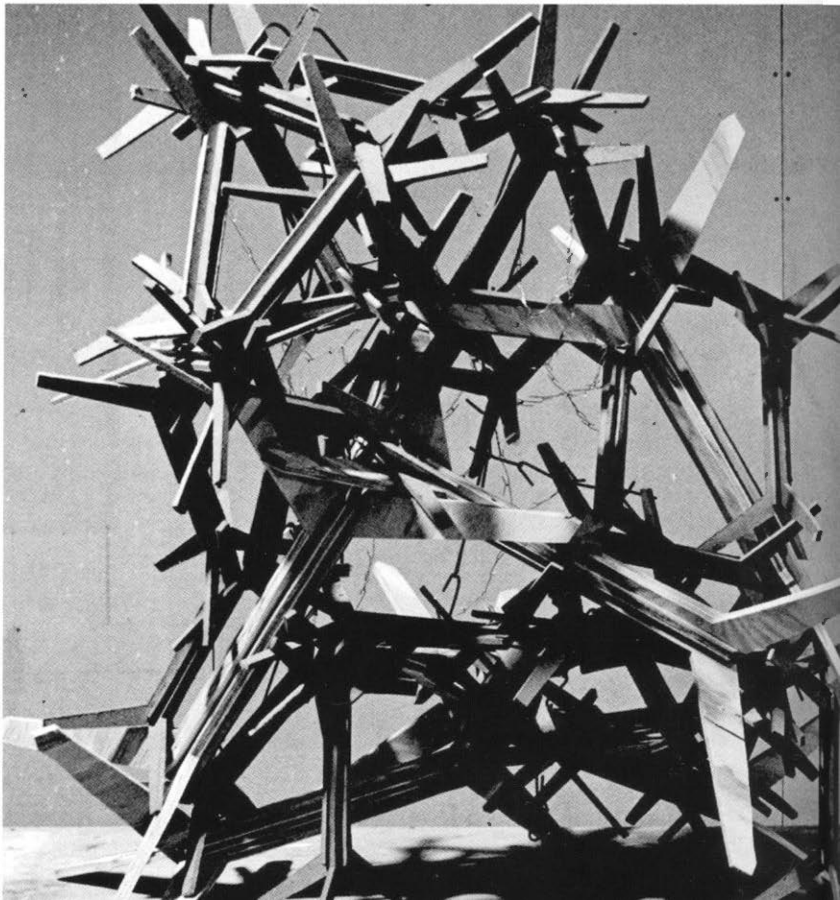


Figure 10.9 Fabrication method via sheet goods

Figure 10.10 Masonite/plywood *Tumbling Units*



Basic geometry

The basic geometry of the unit is conceived as a hybrid of two tetrahedrons attached at a vertex with 30 degrees offset rotation, composing a dumbbell shape. The prongs at both ends of the main axis function as an indeterminate joint condition to cling and/or stack to one another. The member connecting the tetrahedrons gives the capacity to span.

The actual form of the units depends on the material and the production methods. Several alternative designs were investigated and evaluated based on the ease of production, rigidity, density (scale/weight) and esthetic concerns (form/materiality) (Figures 10.8–10.10). This design based on ceramic stoneware proved to be the most desirable, allowing the rigid continuous forming of complex geometry with substantial material quality.[11]

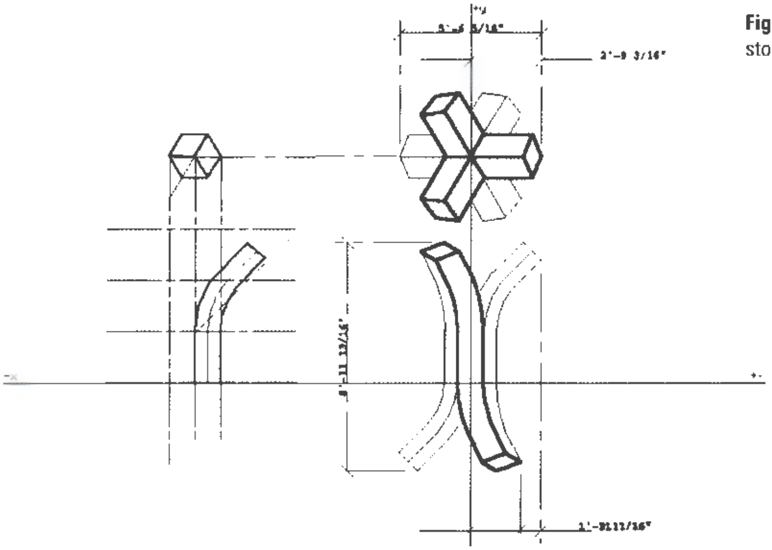


Figure 10.11 Fabrication method in stoneware (ceramic)

Fabrication

There are a number of resistance factors to contend with in fabricating elements of multiplicity. The design parameters were established so that it is feasible for one person to economically produce (1000) units in (30) days using a single 5 c.f. electric kiln.

The property of wet clay is typically characterized as plastic. However, this is not necessarily an accurate description. Clay exhibits an elastic property when the moisture content is relatively low. Its property swings from plastic to elastic depending on the moisture content. The fabrication method exploits this subtle variation of stoneware to the fullest extent.

The pre-mixed stoneware was extruded through a custom-fabricated hexagonal die in approximately 3' length and left to dry for about 45 minutes to the desired stiffness. The strand of extruded clay was then cut to length. Subsequently, both ends were manually split into three prongs and spread into the approximate shape.

The weight and the size of each unit were the critical controlling factors in the production tolerance. It was necessary to carefully balance the drying time required to meet the production schedule against the changing elasticity of the clay prior to firing. The spread of the prong depended on the weight of the unit and the elasticity of the clay. The units were air-dried for approximately two hours at room temperature in an upright position, the sides flipped and dried for an additional three hours to three and a half hours (Figure 10.12). The timing of flipping was also crucial to balance the top and bottom spreads since the unrestricted prongs on top began to close in as the clay dries.

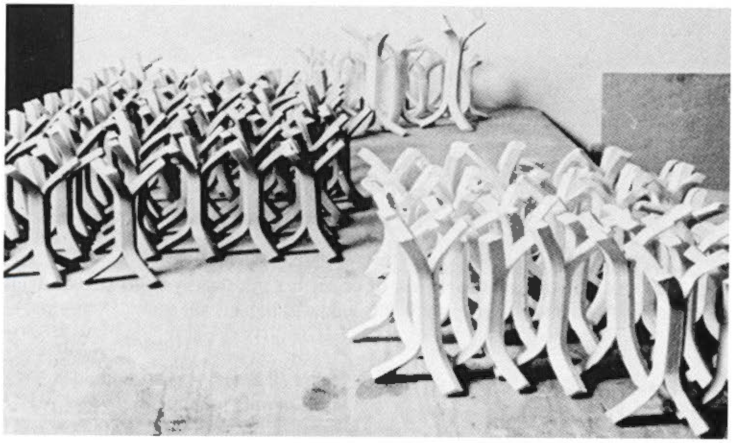


Figure 10.12 Air-drying *Tumbling Units*

Note how the tolerance of form depends on the material's internal response to the gravitational forces, not through a direct artificial manipulation. The external controls imposed are the initial condition and the duration. The material tendencies will take care of the rest. The air-dried units were then loaded in the kiln, fired at cone 2 and left to cool overnight. At the end, over 600 units were produced. One of the unexpected formal outcomes was the unique inflecting surface observed in the unit.

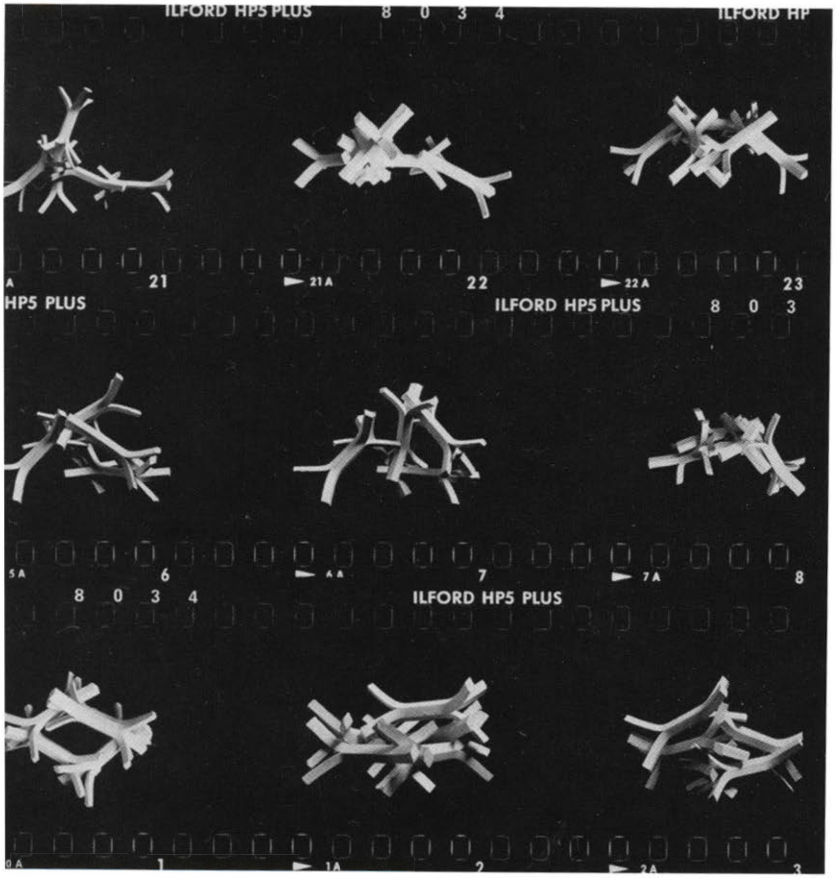


Figure 10.13 Tectonics of four

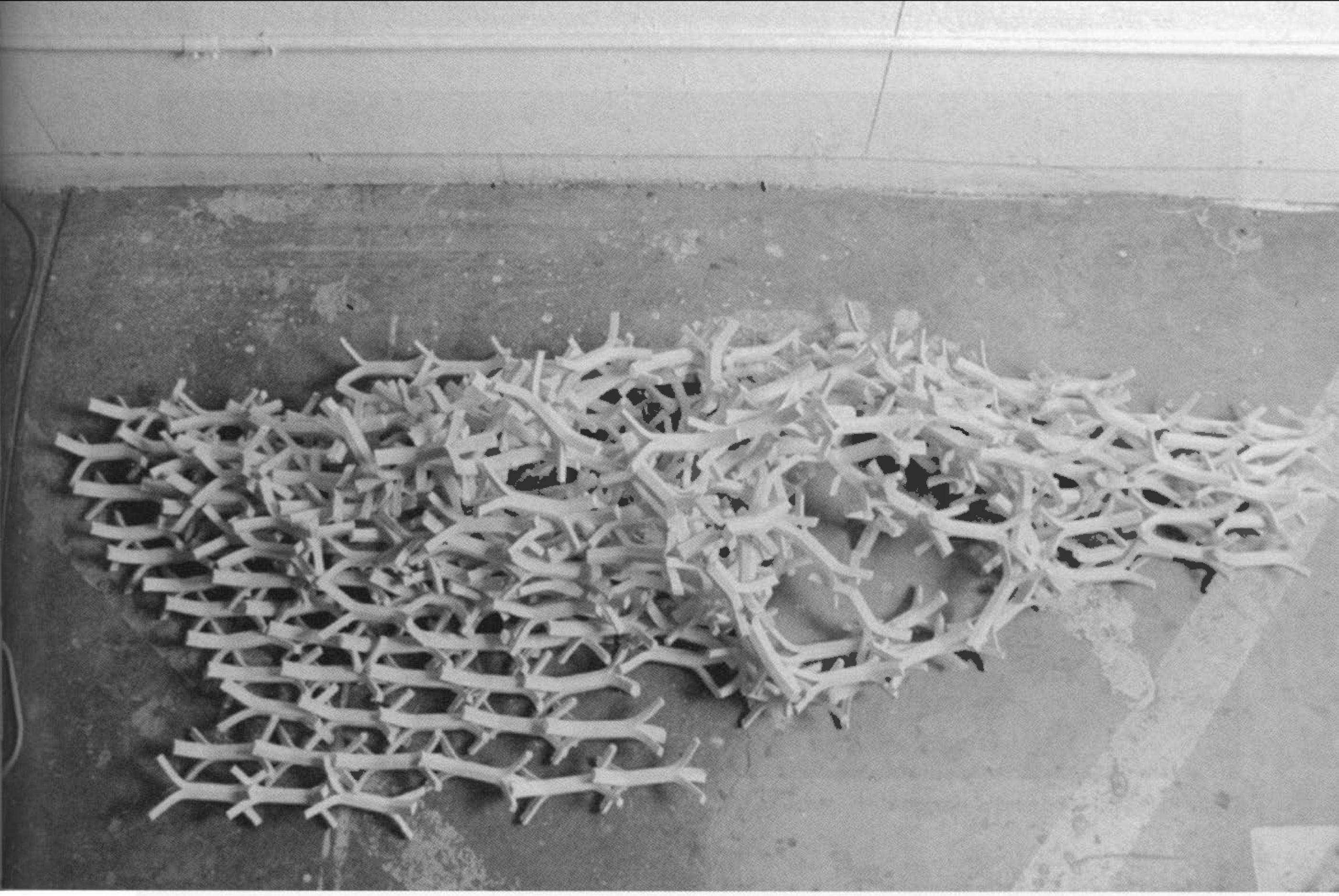
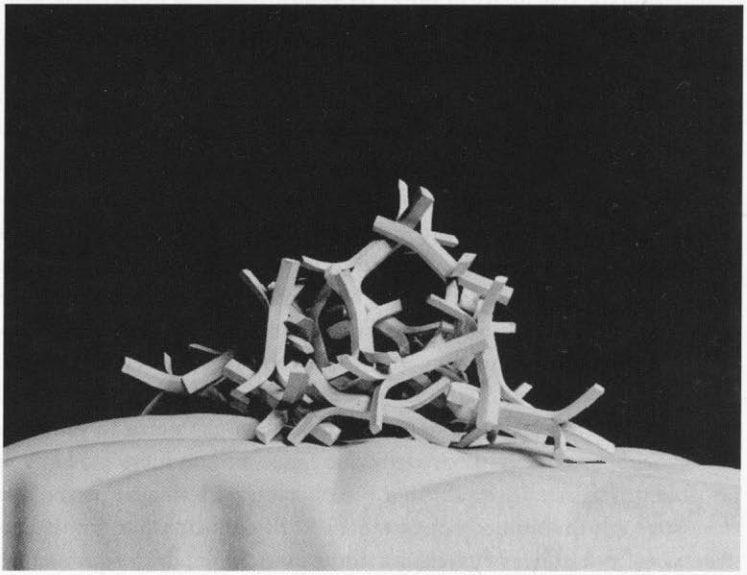


Figure 10.14 Tectonics studies with multiple units

Figure 10.15 Tectonics of nodes



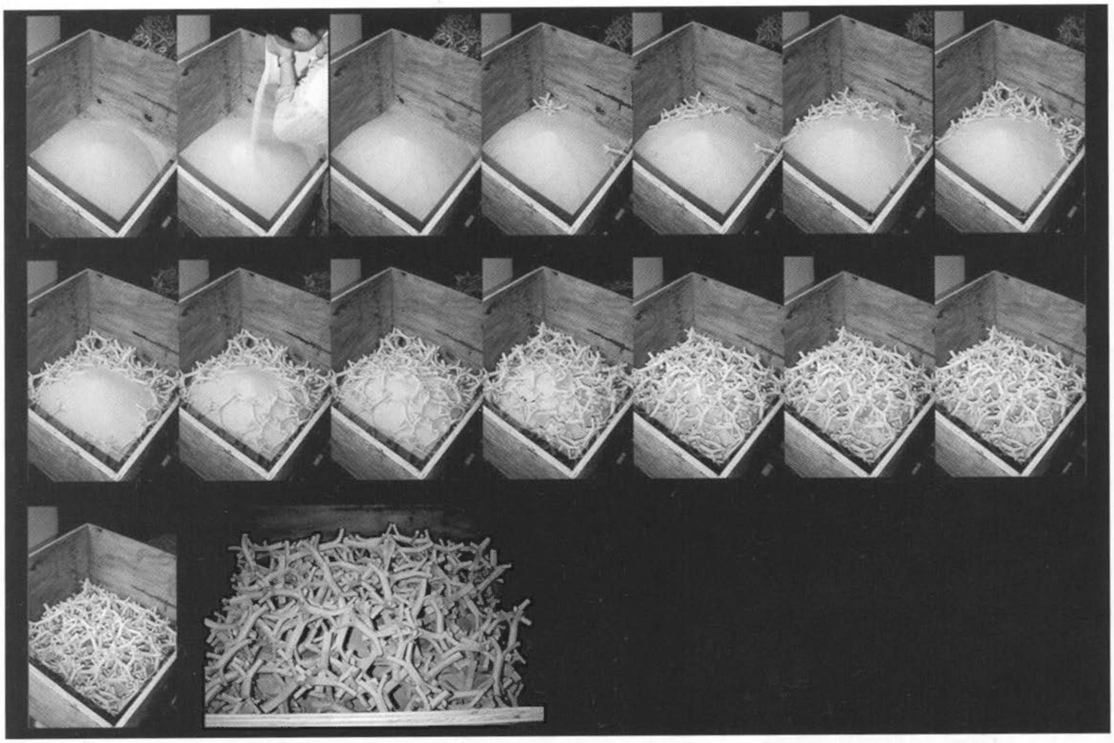


Figure 10.16 Silica sand formwork experiment

Tectonics of an aggregate system

As the production progressed, the behaviors of a small number of units were systemically cataloged. Simultaneously, a larger number of units were employed to explore the range of tectonic possibilities as an aggregate (Figures 10.13–10.14).

Based on observation, a simple extension offers three distinct directional freedoms without considering the specificity of the exact angle in a pair of units. Assume the average number of units consisting of an extension node is three units for an aggregate of 100 units total.

Possible extension combination per node: 3^3 = 27.
Possible node combination in an aggregate of (100): ${}_{100}C_3$ x (1+1/3+1/3+1/3) = 323400[12]

Then, the possible combination (state) of the aggregate reflecting the directional freedom at the nodes: 323400 x 3^3 = 8731800, a rather large sum. The number tells us the magnitude of the possible configuration of the whole aggregate, a step towards quantifying the tectonic characteristics using statistics.

Let us consider what can be quantified as tectonic characteristics of this aggregate. One of the obvious parameters is the number of units composing each extension node. In the previous analysis, we simply assumed the average condition. The further observations reveal that the number can vary somewhere between two and five. It is also clear that these are not randomly assigned numbers. It is the result of an equilibrium reached against the conglomeration of various geometrical, gravitational and contextual influences that can be held constant in the macro scale. Thus, by conducting a large number of empirical experiments, it is possible to statistically establish a distribution pattern against the overall state of the aggregate system. In turn, through the numerically established distribution pattern, it is possible to predict the probability of observing (x) number of extension nodes constituted by (y) number of units in an aggregate system with (z)

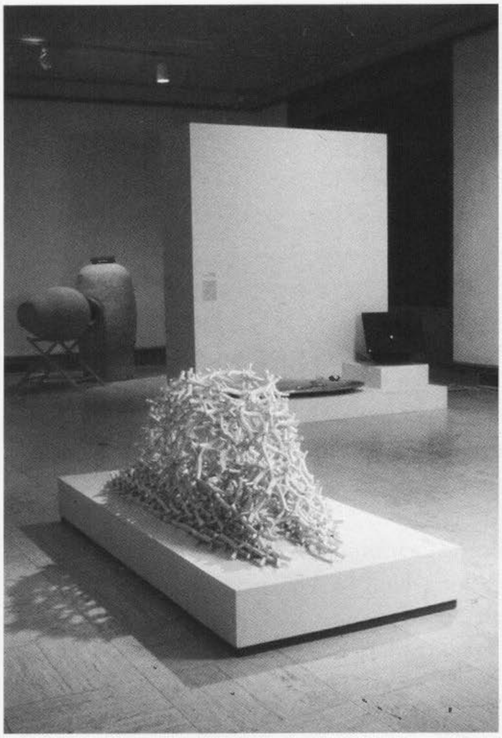


Figure 10.17 *Tumbling Units*: canopy

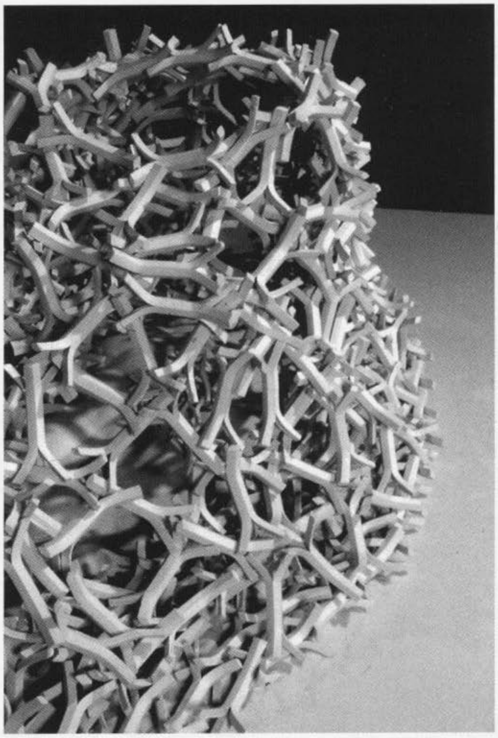


Figure 10.18 *Tumbling Units*: canopy (detail)

number of total units, and so on (Figure 10.15). A role equivalent of the Maxwell–Boltzmann's distribution in statistical mechanics.

Through the introduction of statistics, it is conceivable to establish a "most probable" tectonic characteristic of an indeterminately complex system.

Construction sequence of an indeterminate system

Human judgment involved in the extension of the units is one of the controlling, yet less consistent, macroscopic factors in the earlier tectonic studies. The sensory and motor skill level of the human hand depends on the individual's talent and training. Further, it is impossible to replicate the kind of delicate balancing act human hands are capable of in the scale of building construction.

The skilled labor/judgment issue is a common topic in building construction. In fact, this is one of the reasons why this kind of precision, the ability to virtually map every building component with accuracy, is sought after by such architects as Kieran and Timberlake and Frank Gehry as discussed in the earlier examples. It is an attempt to eliminate the discrepancy between the design and execution by identifying every building part and correlating them one-to-one in the model. The thinking is that by minimizing the unknown, little skilled on-site judgments will be required. The ultimate goal of such a system is for the components to fit together in a predetermined, singular manner.

An alternative approach in deploying the units is speculated and tested in the following example. A mound of silica sand is formed inside an elevated 3' x 3' plywood box. The bottom of the box is designed to evenly drain the sand, sloping to the 1" x 1" center opening. The units were first placed along the edge of the box in higher density to accommodate the anticipated lateral and vertical force transferring into the box. Then the remaining area is loosely filled in with layers. General attention was paid only to the direction of the units to lie evenly distributed against the slope of the sand. As it was drained, the units fell into place and locked into each other seeking a gravitational equilibrium without any external interventions. This resulted in a formation of a shallow dome, spanning across the plywood box (Figure 10.16).

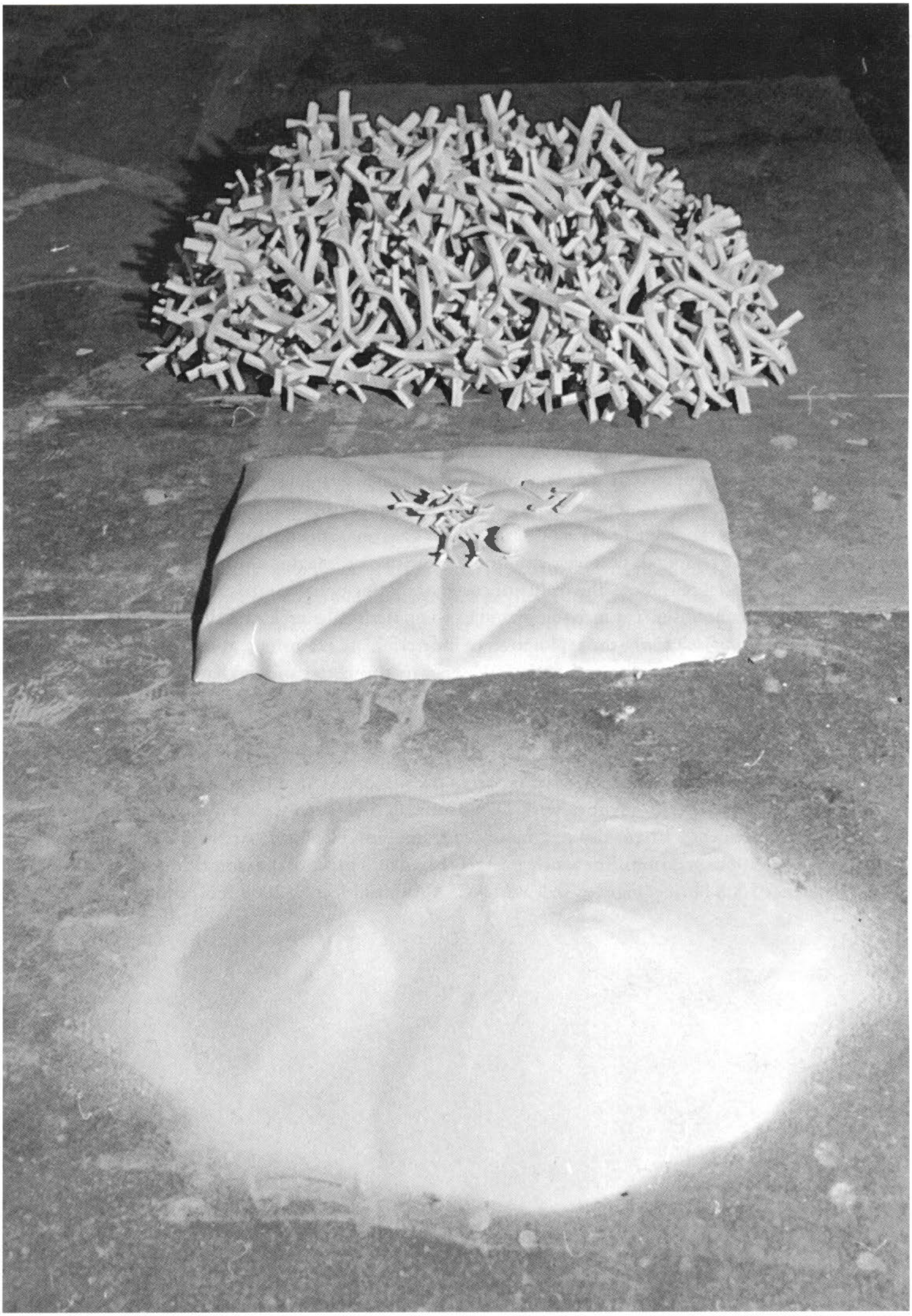
In actual building scale construction, slightly different tactics may be employed substituting the mound of sand with inflatable formwork. Once the elements are roughly placed in position by crane, the formwork is deflated slowly, inducing a similar effect to draining the sand. In this scenario, the skilled on-site judgments are also reduced, however, without relying on computational muscles and the precision necessary for a predetermined system.

Installations

Over and above the basic human need for shelter, archirecture aims to evoke an emotional and intellectual response. Acrobatic forms are often justified as one of the elements of the surprise. However, there are other phenomenal qualities such as materiality, texture, light, shade, time, sequence, scale, proportion and spatial, srructural order. Various aforementioned experiments have culminated in temporary installations for two exhibitions exploring these qualities beyond the acrobaric form. All (600 +/–) units were used for both occasions.

In the first exhibition, the Graduate Degree Exhibition at Cranbrook Art Museum, Bloomfield Hills, Michigan, the units were configured into a self-supporting oblong dome in the size of 3' x 4' x 3'. Exploring the tectonics of spatial/structural order was of prime interest. Attention was paid to the gradual transition from the more ordered configuration at the foundation to more random configurations at the top. A layer

Figure 10.19 *Tumbling Units*: light filter
Figure 10.20 *Tumbling Units*: disassembled



of silica sand stabilized the foundation by filling in the gap, increasing the friction against the platform for lateral support. The viewers were fascinated by the contrasting qualities of the dome; the surprising stability as an assembly despite the delicate qualities of the ceramic units in friction-bound. The museum guards have informed me that there were numerous attempts to touch and to dislodge the units during the two weeks of exhibition in May 1997 (Figures 10.17–10.18).

In the second exhibition, the CoA Faculty Exhibition at Louise Hopkins Underwood Center for the Arts in Lubbock, Texas, the units were stacked against a large storefront window to take advantage of the given context. Exploring the phenomenal qualities of light/shade and scale/proportion were of the prime interest (Figure 10.19).

Conclusion

I have often marveled at the dunescape of the American West: White Sands National Monument in New Mexico, Great Sand Dunes National Park and Preserve in Colorado to name but a few. Standing on the top of the dune crest reminds me of the realization I had under the electron microscope some years ago as a student of physics – that the world consisting of matter we observe daily is not stationary. It is profoundly temporal, tenuous, and imperfect. The amazingly rich phenomenal environment is a result of simple principles governing the interaction of matters, a dynamic equilibrium reached among wind, gravity, and sand particles. Airflow shapes the sand surface. Simultaneously, the surface changes the direction of the airflow and then the modified flow changes the shape of the sand surface. This goes on until computational tendencies of nature works its way out to a temporal stationary condition. How can we imagine a way of shaping matter in this manner for architectural purposes? The reality of current building practice is to execute a complex building efficiently with minimum risks. The technology and its computational muscles are almost exclusively used for this purpose. The *Tumbling Units*, the exploration of indeterminate extensions, aims to raise a fundamental question about the way current architectural practice engages the matter and the act of making.

Acknowledgements

Tumbling Units were designed and fabricated as part of the author's MArch II thesis at Cranbrook Academy of Art in 1996–1997. Thesis advisors were Dan Hoffman and Peter Lynch (Architect in Residence, Architecture Department). I have also sought advice from Tony Hepburn (Artist in Residence, Ceramic Department) on various occasions. The article is largely based on a paper of the same title published in ACSA West Conference 2008 Proceedings[13] as well as in ACSA Annual Meeting 2009 Proceedings.[14]

Notes

1 Michel Serres, “Turner translates Carnot,” in Josue Harari and David Bell, eds., *Hermes: Literature, Science, Philosophy* (Baltimore, MD: The Johns Hopkins University Press, 1982), pp. 56–57.

2 Kobayashi, Keinosuke, Eiji Suito, Shinichi Shimadzu, and Masaya Iwanaga, “Construction of 300 kV Electron Microscope,” *Bulletin of the Institute for Chemical Research*, Kyoto University, 42(6). 1965, 425–438. KURENAI: Kyoto University Research Information Repository. Available at: http://hdl.handle.net/2433/76045.

3 Richard P. Feynman, Robert B. Leighton, and Matthew Sands, eds., *The Feynman Lectures on Physics*, Vol. 1 (Reading, MA: Addison-Wesley Publishing Company Inc., 1970), pp. 38–39.

4 Stephen, Wolfram, *A New Kind of Science* (Champaign, IL: Wolfram Media, Inc., 2002), p. 973.

5 N.L.S. Carnot, “Reflections on the motive power of heat,” ed. R.H. Thurston (New York: John Wiley & Sons, 1897), pp. 37–38.

6 Ibid., p. 147.

7 Stephan Kieran and James Timberlake, *Refabricating Architecture* (New York: McGraw-Hill, 2004), p. 61.

8 Gil Garcetti, Foreword by Frank O. Gehry, *Iron: Erecting the Walt Disney Concert Hall* (Los Angeles: Balcony Press, 2002), p. 8.

9 Gordon E. Moore, “Cramming more components onto integrated circuits,” *Electronics*, 38, 1965.

10 P.P. Gelsinger, P.A. Gargini, G.H. Parker, and A.Y.C. Yu, “Microprocessors circa 2000,” *IEEE Spectrum*, 26(10), October 1989, 43–47.

11 Due to the complexity of its geometry, it requires at least eight part molds to cast a rigid continuous unit. The author has fabricated a few units in this method with marginal success. See Figure 10.8.

12 “nCk” stands for combination: n is the number of objects from which you can choose and k is the number to be chosen.

13 K. Tsubaki, “TUMBLING UNITS: Tectonics of indeterminate extension,” in Gail Peter Borden and Michael Meredith, eds., *Material Matters: Making Architecture* (Washington, DC: ACSA Press, 2008), pp. 284–291.

14 K. Tsubaki, “TUMBLING UNITS: Tectonics of indeterminate extension,” in Phoebe Crisman and Mark Gillem, *The Value of Design: Design Is at the Core of What We Teach and Practice* (Washington, DC: ACSA Press, 2009), pp. 292–298.

"During the past decade a shift occurred that meant that students were often building things rather than modeling them. The first generation that took on that role have set up practices that retroactively begin to re-define education. Michael Meredith and Gail Borden have assembled many of this generation's work and give coherence to this still emerging context. This is work on material qualities and at times capabilities, but perhaps more accurately it reveals a still nascent but deeply important new comfort with fabrication, construction, and the complexity of material as it is embedded within a range of demands from finance to structural performance."

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Gail Peter Borden is principal of the Borden Partnership and an Assistant Professor of Architecture at the University of Southern California. His numerous awards and publications include the Architecture League of New York Young Architects Prize; 2011 AIA Young Architect Award; an artist-in-residence at the Chinati Foundation, the Atlantic Center for the Arts, and the MacDowell Colony; a Graham Foundation Grant; and the Borchard Fellowship.

Michael Meredith is a principal in the architecture office MOS and an Associate Professor of Architecture at the Harvard University Graduate School of Design. His writing has appeared in *Artforum*, *Perspecta*, *LOG*, *Praxis*, *Domus*, and *Harvard Design Magazine*, along with many others. The work of MOS has been widely published and received numerous awards. In 2009, MOS was awarded the PS1/MoMA Summer Pavilion.

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