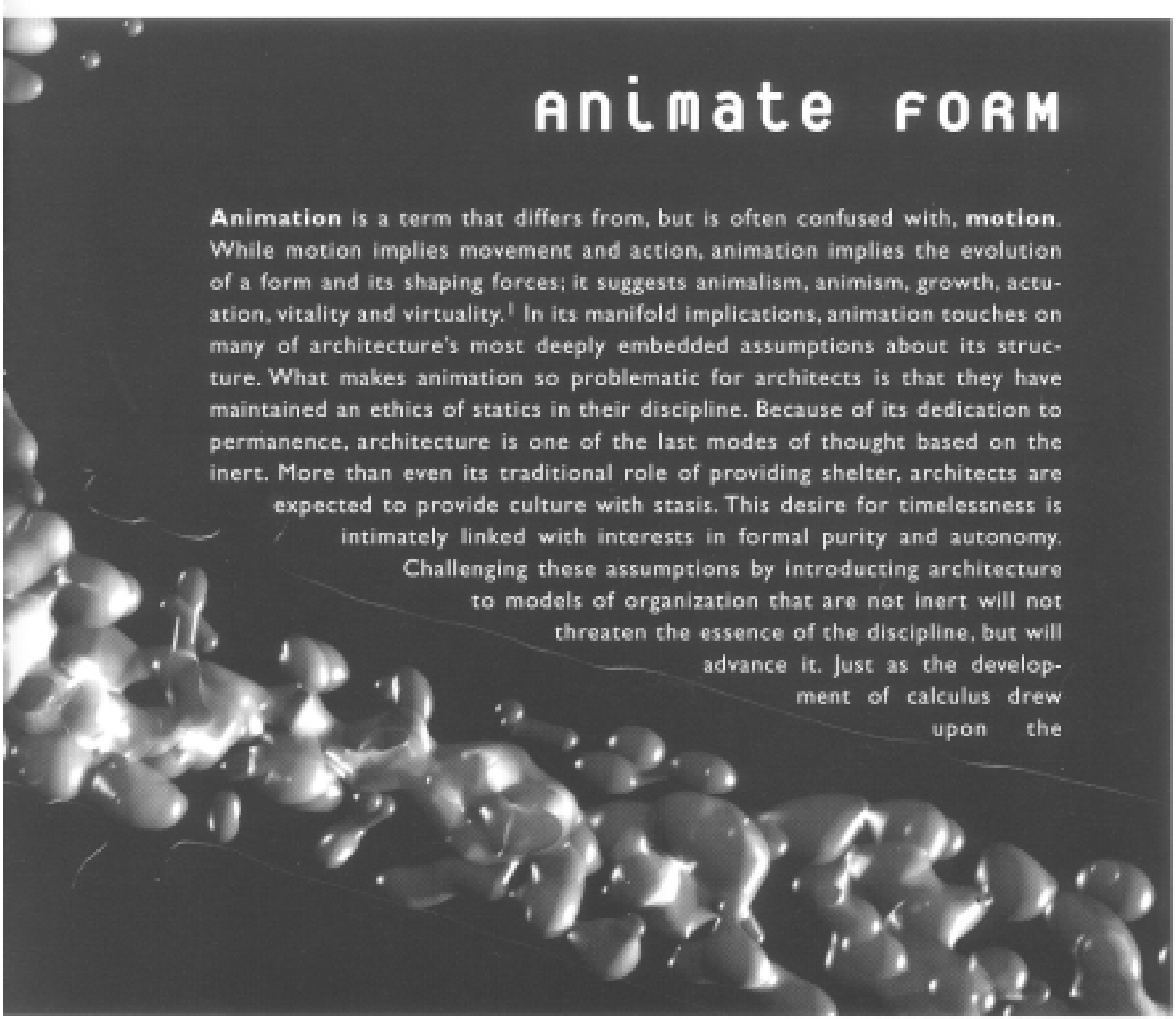


ANIMATE FORM

Animation is a term that differs from, but is often confused with, **motion**. While motion implies movement and action, animation implies the evolution of a form and its shaping forces; it suggests animalism, animism, growth, actuation, vitality and virtuality.[1] In its manifold implications, animation touches on many of architecture's most deeply embedded assumptions about its structure. What makes animation so problematic for architects is that they have maintained an ethics of statics in their discipline. Because of its dedication to permanence, architecture is one of the last modes of thought based on the inert. More than even its traditional role of providing shelter, architects are expected to provide culture with stasis. This desire for timelessness is intimately linked with interests in formal purity and autonomy. Challenging these assumptions by introducting architecture to models of organization that are not inert will not threaten the essence of the discipline, but will advance it. Just as the development of calculus drew upon the historical mathematical developments that preceded it, so too will an animate approach to architecture subsume traditional models of statics into a more advanced system of dynamic organizations. Traditionally, in architecture, the abstract space of design is conceived as an ideal neutral space of Cartesian coordinates. In other design fields, however, design space is conceived as an environment of force and motion rather than as a neutral vacuum. In naval design, for example, the abstract space of design is imbued with the properties of flow, turbulence, viscosity, and drag so that the form of a hull can be conceived in motion through water. Although the form of a boat hull is designed to anticipate motion, there is no expectation that its shape will change. An ethics of motion neither implies nor precludes literal motion. Form can be shaped by the collaboration between an envelope and the active context in which it is situated. While physical form can be defined in terms of static coordinates, the virtual force of the environment in which it is designed contributes to its shape.The particular form of a hull stores multiple vectors of motion and flow from the space in which it was designed. A sailboat hull, for example, is designed to perform under multiple points of sail. For sailing downwind, the hull is designed as a planing surface. For sailing into the wind, the hull is designed to heal, presenting a greater surface area to the water. A boat hull does not change its shape when it changes its direction, obviously, but variable points of sail are incorporated into its surface. In this way, topology allows for not just the incorporation of a single moment but rather a multiplicity of vectors, and therefore, a multiplicity of times, in a single continuous surface.

Likewise, the forms of a dynamically conceived architecture may be shaped in association with virtual motion and force, but again, this does not mandate that the architecture change its shape. Actual movement often involves a mechanical paradigm of multiple discrete positions, whereas virtual movement allows form to occupy a multiplicity of possible positions continuously with the same form.

The term **virtual** has recently been so debased that it often simply refers to the digital space of computer-aided design. It is often used interchangeably with the term simulation. Simulation, unlike virtuality, is not intended as a diagram for a future possible concrete assemblage but is instead a visual substitute. "Virtual reality" might describe architectural design but as it is used to describe a simulated environment it would be better replaced by "simulated reality" or "substitute reality." Thus, use of the term virtual here refers to an abstract scheme that has the possibility of becoming actualized, often in a variety of possible configurations. Since architects produce drawings of buildings and not buildings themselves, architecture, more than any other discipline, is involved with the production of virtual descriptions.

There is one aspect of virtuality that architects have neglected, however, and that is the principle of virtual force and the differential variation it implies. Architectural form is conventionally conceived in a dimensional space of idealized stasis, defined by Cartesian fixed-point coordinates. An object defined as a vector whose trajectory is relative to other objects, forces, fields and flows, defines form within an active space of force and motion. This shift from a passive space of static coordinates to an active space of interactions implies a move from autonomous purity to contextual specificity.2 Contemporary animation and special-effects software are just now being introduced as tools for design rather than as devices for rendering, visualization and imaging.3

The dominant mode for discussing motion in architecture has been the cinematic model, where the multiplication and sequencing of static snap-shots simulates movement. The problem with the motion-picture analogy is that architecture occupies the role of the static frame through which motion progresses. Force and motion are eliminated from form only to be reintroduced, after the fact of design, through concepts and techniques of optical procession.

In contrast, animate design is defined by the co-presence of motion and force at the moment of formal conception. Force is an initial condition, the cause of both motion and the particular inflections of a form. For example, in what is called *"inverse kinematic"* animation, the motion and shape of a form is defined by multiple interacting vectors that unfold in time perpetually and openly. With these techniques, entities are given vectorial properties before they are released into a space differentiated by gradients of force. Instead of a neutral abstract space for design, the context for design becomes an active abstract space that directs form within a current of forces that can be stored as information in the shape of the form. Rather than as a frame through which time and space pass, architecture can be modeled as a participant immersed within dynamical flows. In addition to the special-effects and animation industries, many other disciplines such as aeronautical design, naval design, and automobile design employ this animate approach to modeling form in a space that is a medium of movement and force.

Previous architectural experiments in capturing motion have involved the superimposition of simultaneous instances.The superimposition of a sequence of frames produces memory in the form of spatio-temporal simultaneity. This idea of an architecture in which time is built into form as memory has been a persistent theme throughout its history, but it was Sigfried Giedion in both *Mechanization Takes Command (1948)* and *Space, Time, and Architecture (194 I)* who established these themes as the primary concern of twentieth-century

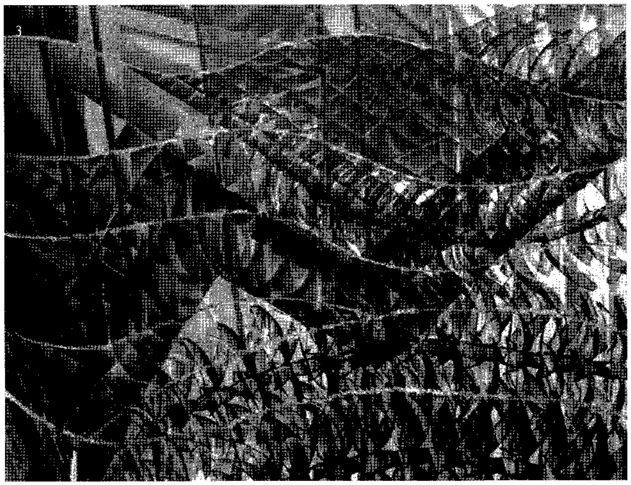


Figure 1:
Bucharest urban design competition study using particle animation flows to define variable densities across the site.

Figure 2:
Marcel Duchamp, *Nude Descending a Staircase, No. 2* (1912) Philadelphia Museum of Art, Louise and Walter Arensberg Collection.

Figure 3:
Umberto Boccioni, *Dynamism of a Soccer Player* (1913). Museum of Modern Art, New York, The Sidney and Harriet Janis Collection.

architectural theory and design.[4] Giedion included both cubist and futurist approaches to capturing motion in form, using as examples the work of Marcel Duchamp (fig. 2) and Umberto Boccioni (fig. 3). Giedion's interpretation of these cubo-futurist experiments continues to influence contemporary design and theory.s In both approaches, multiple static frames of an object in time are captured and superimposed in the same space simultaneously, generating a temporal palimpsest.

Another model of indexical time is associated with Colin Rowe and his disciples. In Rowe's text, "Transparency: Literal and Phenomenal," co-authored with Robert Slutzky, the idea of a formal, or phenomenal, transparency is proposed along with literal transparency.b Phenomenal transparency is the tracing or imprinting of a deeper formal space on a surface. Similarly, examples of formal or phenomenal time include "shearing," "shifting," and "rotating" operations. Superimposed snap-shots of motion imply time as a phenomenal movement between frames or moments. For instance, Kenneth Frampton's description of Charles Gwathmey's early work as "rotational" is one such example of time being used to describe the movement between superimposed, formal moments.? Another example is that of the "trace," a term that has emerged in the last twenty years as a graphical notation of time and motion in architecture.8 In such projects, a design process of sequential formal operations is recorded in the building's configuration through colors, alignments, imprints, additions and subtractions. One such example is the simultaneous presence of multiple historical ground conditions at a single moment. The intervals between the moments that are superimposed generate irresolute conditions which are exploited for their destabilizing effect on the present.

In all of these indexical responses to time, a superimposition or sequence of static forms is put into relation such that the viewer resolves multiple states through the initiation of optical motion. Although form is thought in series and motion in these examples, movement is something that is added back to the object by the viewer. This involves a dialectic definition of motion that assumes that matter is inert while our experience of it involves movement. Statics becomes the condition of matter without force and dynamics becomes the condition of matter acted on by force. Both positions assume that force is something which can be added or subtracted from matter.

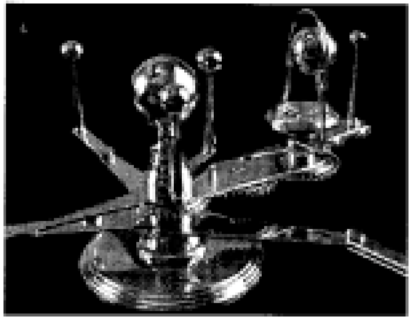
The modeling of architecture in a conceptual field populated by forces and motion contrasts with these previous; paradigms and technologies of formal stasis. Stasis is a concept which has been intimately linked with architecture in at least five important ways, including I) permanence, 2) usefulness, 3) typology, 4) procession, and 5) verticality. However, statics does not hold an essential grip on architectural thinking as much as it is a lazy habit or default that architects either choose to reinforce or contradict for lack of a better model. Each of these assumptions can be transformed once the virtual space in which architecture is conceptualized is mobilized with both time and force. With the example of permanence, the dominant cultural expectation is that buildings must be built for eternity when in fact most buildings are built to persist for only a short time. Rather than designing for permanence, techniques for obsolescence, dismantling, ruination, recycling and abandonment through time warrant exploration. Another characteristic of static models is that of functional fixity. Buildings are often assumed to have a particular and fixed relationship to their programs, whether they are intersected, combined or even flexibly programmed. Typological fixity, of the kind promoted by Colin Rowe for instance, depends on a closed static order to underlie a family of continuous variations. This concept of a discrete, ideal, and fixed prototype can be subsumed by the model of the numerically controlled multi-type that is flexible, mutable, and differential. This multi-type, or **performance envelope,** does not privilege a fixed type but instead models a series of relationships or expressions between a range of potentials. Similarly, independent interacting variables can be linked to influence one another through logical expressions defining the size, position, rotation, direction, or speed of an object by looking to other objects for their characteristics. This concept of an envelope of potential from which either a single or a series of **instances** can be taken, is radically different from the idea of a fixed prototype that can be varied.

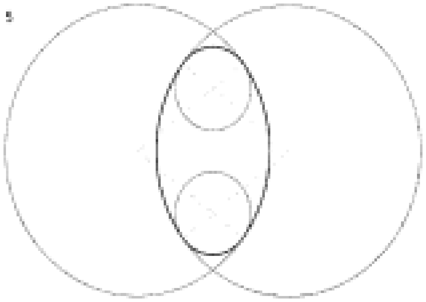
Finally, static models underwrite the retrograde understanding of gravity as a simple, unchanging, vertical force. Architecture remains as the last refuge for members of the flat-earth society. The relationships of structure to force and gravity are by definition multiple and interrelated, yet architects tend to reduce these issues to what is still held as a central truth: that buildings stand up vertically. In fact, there are multiple interacting structural pressures exerted on buildings from many directions, including lateral wind loads, uplift, shear, and earthquakes, to name a few of the non-vertical conditions. Any one of these **live** loads could easily exceed the relative weight of the building and its vertical **dead** loads. The naive understanding of structure as primarily a problem of the vertical transfer of dead gravity loads to the ground excludes, for instance, the fact that lighter buildings have a tendency to uplift; the main structural concern in these cases is how to tether the roof. Of course architects and structural engineers do not ignore these other structural factors, but the primary perception of structure has always been that it should be vertical. A reconceptualization of ground and verticality in light of complex vectors and movements might not change the expediency and need for level floors, but it would open up possibilities for structure and support that take into account ’orientations other than the simply vertical.

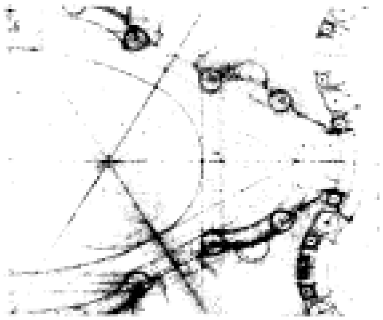
These concerns are not merely technical as architecture presently expresses also the cultural diagrams of stasis. Despite the popular conception among architects that gravity is a fact, the contemporary debates about theories of gravity could inform present discussions of architecture in the same spirit that they have done in the past. The history of theories of gravity are extremely nuanced, fascinating and unresolved. Since the time of Sir Isaac Newton, gravity has been accepted as the mutual relative attraction of masses in space. Given a constant mass, stability is achieved through orbits rather than stasis. This distinction between stasis and orbital or dynamic stability is important. In the case of a single, simple gravity, **stasis** is the ordering system through the unchanging constant force of a ground point. In the case of a more complex concept of gravity, mutual attraction generates motion; **stability** is the ordering of motion into rhythmic phases. In the simple, static model of gravity, motion is eliminated at the beginning. In the complex, stable model of gravity, motion is an ordering principle. Likewise, discreteness, timelessness, and fixity are characteristic of stasis; multiplicity, change, and development are characteristic of stability.

These differences are very apparent in the two models of gravity debated by Rene Descartes and Gottfried Wilhelm Leibniz. Descartes isolated and reduced elements in a dynamic system to their constitutive identities to create a steady-state equation: he eliminated time and force from the equation in order to calculate a precise position. Leibniz, on the other hand, examined components within their contextual field of influences and within a developing temporal continuum. By retaining the creative structural role of time and force, Leibniz determined that a position in space can only be calculated continuously as a vectoral flow.9 The name that he attributed to any provisionally reduced component or primitive element is that of the *"monad."* Where Newton used calculus to replace the zero value of statics with a *"derivative,"* Leibniz formulated the concept of the *"integral,"* where within any monad there is a kernel of the whole equation in the form of the variables. Any monad has the ability to unfold a *"possible world."* Thus integral calculus is structured on a monad logic of continuous multiplicity. The shift from a discrete model of 'gravity as a force that could be eliminated from matter, to a concept of gravity as integral and continuous with masses in space, involves a redefinition of space from being neutral and timeless to being temporally dynamic. Once design is posed within a Leibnizian monadological space, architecture may embrace a sensibility of micro and macro contextual specificity as a logic that can not be idealized in an abstract space of fixed coordinates. In such an abstract active space, the statics of fixed points in neutral space is replaced by the stability of vectors that balance one another in a phase space.

If architecture is to approach this more complex concept of gravity, its design technologies should also incorporate factors of time and motion. Throughout the history of architecture, descriptive techniques have impacted the way in which architectural design and construction has been practiced. In the eighteenth century, the orrery (fig. 4) came to represent not only the image of the machine but also the conceptual processes of a universe that is harmonically regulated as a closed system of circular orbits around radial center points. Because an orrery uses fixed radial points, any discrete moment in time can be calculated as a fixed point. The compass, like the orrery, has implicit in it a series of conceptual and disciplinary limits that are rehearsed with every arc that is drawn. Events such as the advent of perspective, stereometric projection, and other geometric techniques have extended the descriptive repertoire of architectural designers.







In our present age, the virtual space within which architecture is conceived is now being rethought by the introduction of advanced motion tools and a constellation of new diagrams based on the computer. The geometry and the mathematics that Leibniz invented to describe this interactive, combinatorial, and multiplicitous gravity remain as the foundations for topology and calculus upon which contemporary animation technology is based. There can be little doubt that the advent of computer-aided visualization has allowed architects to explore calculus-based forms for the first time.

The sequential continuity of more than two variables interacting with one another poses a problem that only calculus can answer. First posed by Karl Weierstrass, Charles Hermite and Gosta Mittag-Lefler in 1885, the "nbody" problem was later made famous by Henri Poincare in 1889, when he was able to prove that no discrete solution for such a problem could exist. The fundamental aspect of this problem, referred to as "the Poincare threebody problem," is that the temporal and spatial position of entities cannot be mathematically calculated for a future position without sequentially calculating the positions leading up to that moment. The mathematics of form and space that architects have historically understood, involve mathematical descriptions from which time has been eliminated. In the three-body problem however, time, or more properly duration and sequence, are integral to the spatial relationships being calculated. Another aspect of this kind of relationship in which three or more objects interact, is that they often produce nonlinear behavior.The method by which these problems can be calculated is through a mathematics that is sequential and continuous: thus the invention by both Newton and Leibniz of differential calculus.

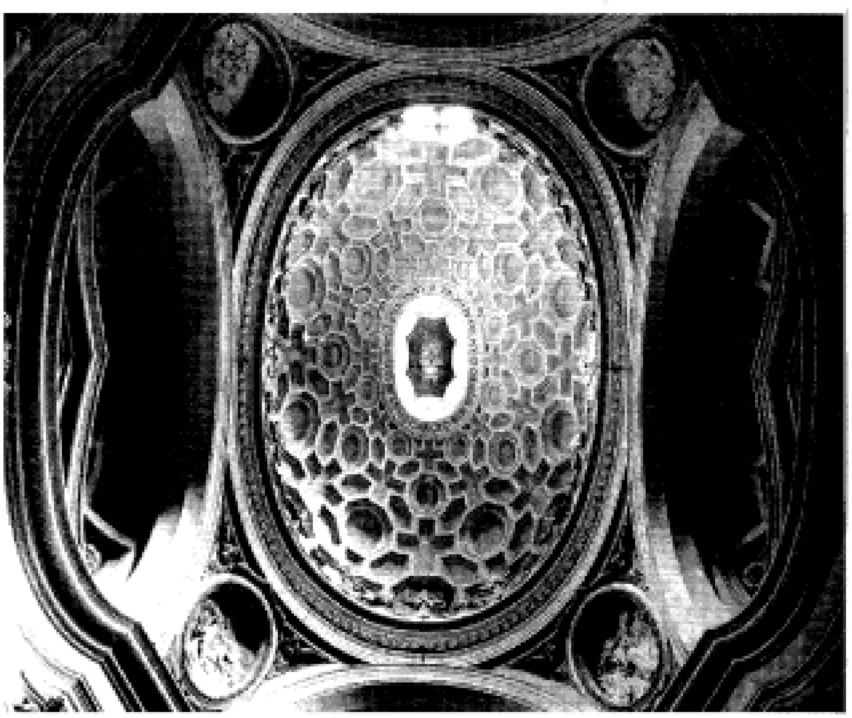
Although the mechanical, acoustic, and structural systems of buildings have been calculated and conceived using the tools of calculus, architects infrequently use calculus for the design of form.The fact that architecture is so heavily dependent on mathematics for the description of space has been a

Figure 4:
Reproduction of the apparatus commissioned by Charles Boyle, 4th Earl of Cork and Orrery, showing the relative positions and motions of bodies in the solar system by balls moved by wheelwork. Reproduction by Van Cort Instruments, Inc.

Figure 5:
An elipse constructed with four circles with four radii. The connecting lines between the radii become the points of tangency where the composite curves change from being defined in relation to one radius to another.

Figure 6:
Plan detail of Borromini's sketch for "Quattro Fontane" Church of San Carlo, showing the use of complex composite curves constructed out of linked segments of circles and spheres. From Anthony Blunt, *Vita e opere di Borromini* (Rome: Editori Laterza, 1983), 51.

Figure 7:
A ceiling detail of the cupola of Borromini's "Quattro Fontane." From Anthony Blunt, *Vita e opere di Borromini* (Rome: Editori Laterza, 1983), 51.



stumbling block to the use of motion and flow in the design process, as these ideas require that architects draw geometries whose underlying mathematics is calculus. The tools that architects use to draw, such as adjustable triangles and compasses, are based on simple algebra. The prevalence of topological surfaces in even the simplest CAD software, along with the ability to tap the time-and-force modeling attributes of animation software, presents perhaps the first opportunity for architects to draw and sketch using calculus. The challenge for contemporary architectural theory and design is to try to understand the appearance of these tools in a more sophisticated way than as simply a new set of shapes. Issues of force, motion and time, which have perennially eluded architectural description due to their "vague essence," can now be experimented with by supplanting the traditional tools of exactitude and stasis with tools of gradients, flexible envelopes, temporal flows and forces. 10

As architects have been disciplined to eliminate questions of flow and motion from the rigorous description of space, these qualities have been relegated to personal taste and casual definition. Because of the present lack of experience and precedent with issues of motion and force in archi-

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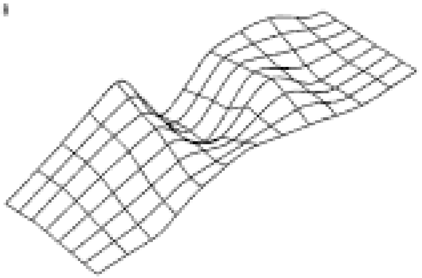

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Figure 8:
A spline surface drawn with vectors that hang from points.

Figure 9:
The spline surface after being converted to triangular polygons.

tecture, these issues might best be raised from within the technological regimes of the tools rather than from within architectural history.

Through experimentation with non-architectural regimes, architects may discover how to engage time and motion in design. The computer has already proven to be useful as both a descriptive and a visualizing tool to architects, but the introduction of time and motion techniques into architecture is not simply a visual phenomenon. The visual qualities of computer-generated images may be important but it seems misguided to understand geometry in terms of style. The invention of stylistic categories risks the reproduction of the same spurious comparisons of modern architecture to boats and aircraft based on the similarity of shapes. For instance, although geodesic domes often employ triangulated surfaces and some computer programs convert vector surfaces to fixed points through the use of triangular polygon meshes (figs. 8 and 9), it is a very shallow comparison to equate architecture designed using topological surfaces to Buckminster Fuller simply because of the commonality of triangulated surfaces.1z

Nonetheless, there are distinct formal and visual consequences of the use of computer animation. For instance, the most obvious aesthetic consequence is the shift from volumes defined by Cartesian coordinates to topological surfaces defined by U and V vector coordinates (fig. 12). Another obvious aesthetic byproduct of these spatial models is the predominance of deformation and transformation techniques available in a time-based system of flexible surfaces (fig. 13). These are not merely shapes but the expression of the mathematics of the topological medium.

In addition to the aesthetic and material consequences of computer-generated forms, computer software also offers capabilities as a conceptual and organizational tool. But because of the stigma and fear of releasing control of the design process to software, few architects have attempted to use the computer as a schematic, organizing and generative medium for design. The limits and tendencies of this tool, as a medium for design, must be clearly understood conceptually before they can be grasped by a systematic intuition.[13]

There are also some misconceptions about the role of computers in the design process. A precious few architectural designers and theorists, Karl Chu and John Frazer being the most lucid among them, argue for the creative capacity of computers to facilitate genetic design strategies. The genetic, or rule-based, phenomenon of computation should not be discounted. Yet at the same time, genetic processes should not be equated with either intelligence or nature. The computer is not a brain. Machine intelligence might best be described as that of mindless connections. When connecting multiple variables, the computer simply connects them, it does not think critically about how it connects. The present limits of connectionism are staggeringly complex, and the directness with which multiple entities can be related challenges human sensibility. The response has been to attempt to develop a commensurate sensibility in the machines themselves; but the failures of artificial intelligence suggest a need to develop a systematic human intuition about the connective medium, rather than attempting to build criticality into the machine. Even in the most scientific applications of computer simulations it is argued that first an intuition must be developed in order to recognize the nonlinear behavior of computer simulations.14 Also, the computer is not nature. Although it makes shapes that are temporally and formally open to deformation and inflection, those shapes are not organic. The organic appearance of what will later be discussed as a system of interaction and curvilinearity is a result of organizational principles based on differentials. The formal organizations that result from the sequential mathematical calculation of differential equations are irreducibly open in terms of their shape. They are often interpreted as organic because of the inability to reduce these shapes to an ideal form. In contrast, the reducible, fixed forms of simple mathematics-such as spheres, cubes, pyramids, cones and cylinders-have a simplicity and purity that allows them to transcend their formal particularities.

Instead of approaching the computer as either a brain or nature, the computer might be considered as a pet. Like a pet, the computer has already been domesticated and pedigreed, yet it does not behave with human intelligence. Just as a pet introduces an element of wildness to our domestic habits that must be controlled and disciplined, the computer brings both a degree of discipline and unanticipated behavior to the design process. By negotiating the degree of discipline and wildness, one can cultivate an intuition into the behavior of computer-aided design systems and the mathematics behind them.

There are three fundamental properties of organization in a computer that are very different from the characteristics of inert mediums such as paper and pencil: **topology, time, and parameters.** These three properties should be discussed, beginning with the principles of topological entities, continuing with the implications that topological forms raise for the relationship between time and shape, and concluding with a discussion of statistics and parameters that can be stored in these timed surfaces.

One of the first principles of topological entities is that because they are defined with calculus they take the shape of a multiplicity; meaning they are not composed of discrete points but rather, they are composed of a continuous stream of relative values. Historically, baroque geometries of composite entities, such as multiple radii, have been cited as multiplicitous spaces. But the idea that the baroque period anticipates topology in architecture is somewhat misplaced. There is a critical difference between the discrete geometry of baroque space-a geometry of multiple points, and the continuity of topology-a multiplicity without points. Where baroque space is defined by multiple radii, a topological surface is defined as a flow that hangs from fixed points that are weighted. Although baroque space is geometrically highly continuous and highly differentiated, it does retain multiple spatial centers. The continuous contours of baroque interiors are composed of segments of multiple discrete radial elements (figs. 5 and 10). For example, in Francesco Borromini’s Quattro Fontane the complex of primitive volumes is tangentially aligned to produce a continuous surface, giving the space simultaneous dynamism and centrality (figs. 6 and 7). The relationships between these radial primitives are often of bilaterally symmetry and always of tangency.

Instead of being defined by points and centers, topology is characterized by flexible surfaces composed of splines (fig. 11).These splines are oriented in an opposing U and V orientation to construct surfaces composed of curve networks (fig. 19). Unlike lines, splines are vectors defined with direction. The vectors are suspended from lines with hanging weights similar to the geometry of a catenoidal curve.15 Yet unlike a catenoidal curve, a spline can accommodate weights and gravities directed in free space. The points, or "control vertices," from which these weights hang, and through which the

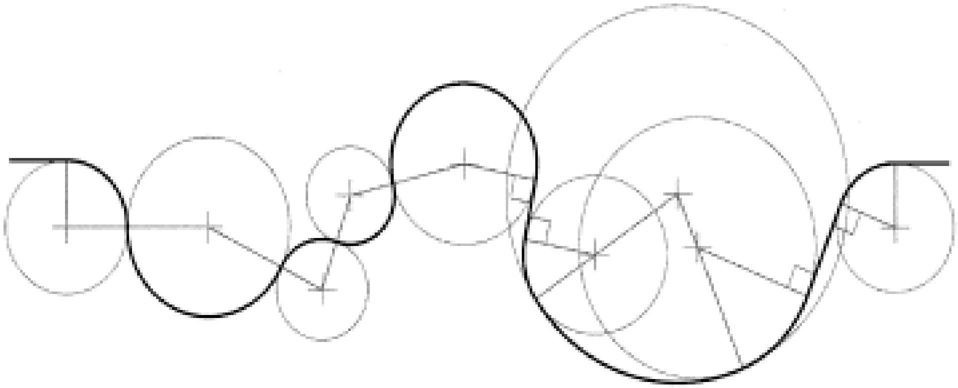

Figure 10:
An example of a composite curve using the same logic of regional definition and tangency as the ellipse described in Figure 5. Each section of the composite curve is defined by a fixed radius. The connection between radial curve segments occurs at points of tangency that are defined by a line connecting the radii. Perpendicular to theses lines, straight line segments can be inserted between the radial curves.

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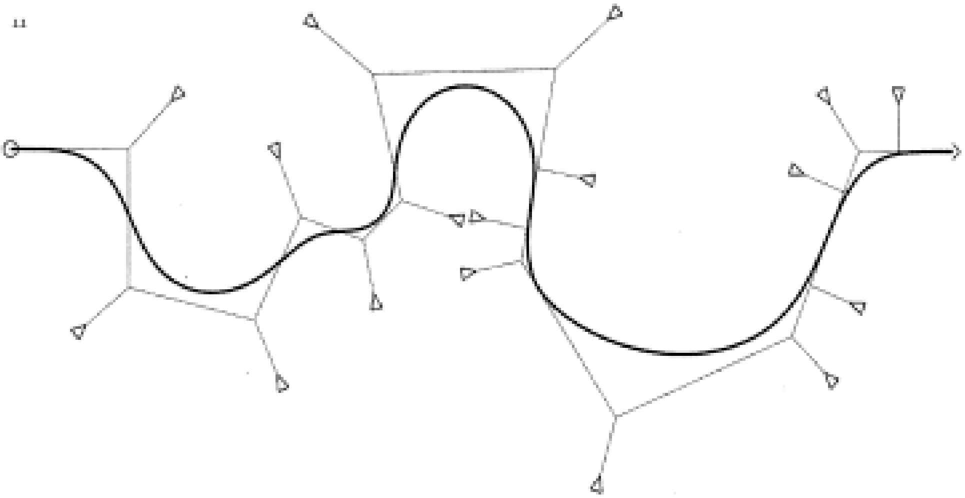

Figure 11:
A similar curve described using spline geometry, in which the radii are replaced by control vertices with weights and handles through which the curved spline flows.

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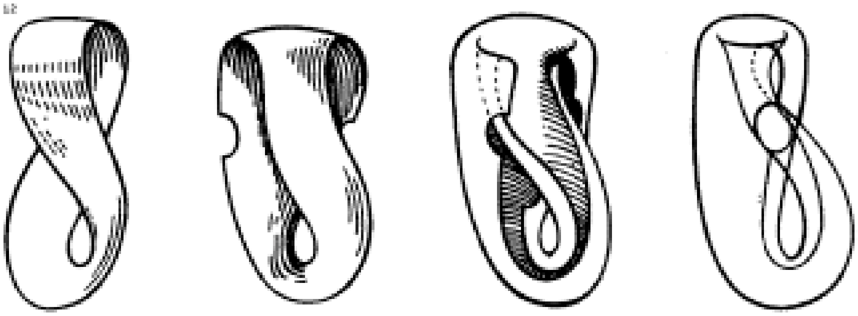

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Figure 12:
A spline surface that begins as a twisted mobius band and is stretched and joined along its edges to form a self-intersecting surface. Enclosed volumes are trapped within the surface by both the joining and intersecting operations. From Stephen Barr, *Experiments in Topology* (New York: Dover Publications, Inc., 1964), 69.

Figure 13:
A transformation of a ring into a cup through the flexibility of a single surface. From Stephen Barr, *Experiments in Topology* (New York: Dover Publications, Inc., 1964), 4.

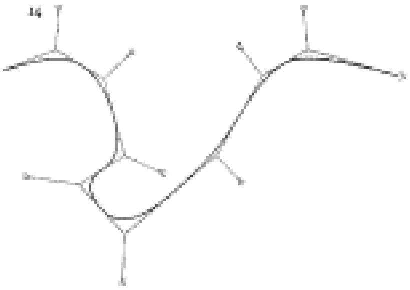
spline flows, are located in X, Y, Z coordinate space. From a sequence of control vertices the direction and strength of weights establishes a tension along the hulls.Although the control vertices, hulls, and weights are defined in a point-based, Cartesian, space, the splines are not defined as points but as flows. The spline curve is unlike a line or radius in that its shape is not reducible to exact coordinates. The spline curve flows as a stream between a constellation of weighted control vertices and any position along this continuous series can only be defined relative to its position in the sequence. The formal character of a particular spline is based on the number of control vertices influencing a particular region of the flow. For instance, a three-degree spline (fig. 14) will begin at its root and determine its inflection between every three points in a series. A seven-degree spline curve (fig. 15) will be defined by groups of seven control vertices, thus appearing smoother. A two-degree spline (fig. 16) will appear linear because it lacks smooth continuity between control vertices. Even though the control vertices remain constant in these examples, the particular shape changes due to the degree of relative definition of the controlling points of the sequential flow. Similarly, without changing the position of any one of the control vertices or the degree of the spline, the shape will be altered when the weight or direction of any of the normals is altered (fig. 18).

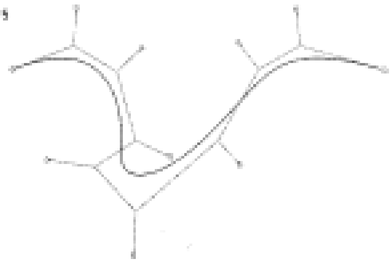
A change in any point distributes an inflection across regions of these entities. Because splines are vectorial flows through sequences of points they are by definition continuous multiplicities rather than discrete entities. A multiplicity is a collection of components that is neither reducible to a single entity nor to a collection of multiple entities. A multiplicity is neither one nor many, but a continuous assemblage of heterogeneous singularities that exhibits both collective qualities of continuity and local qualities of heterogeneity. In the use of topology in design, these multiplicities imply a very different approach to location, as there are no discrete points along a spline.

The two linked principles that are central to the temporal component of topology are (I) the immanent curvatures that result from the combinatorial logic of differential equations and (2) the mathematical cause of that curvature. Because topological entities are based on vectors, they are capable of systematically incorporating time and motion into their shape as inflection. Inflection, or continuous curvature is the graphical and mathematical model for the imbrication of multiple forces in time.The shift. from linearity to curvilinearity is a feature of contemporary mathematics and geometry that has been discussed elsewhere.1b Curvilinearity is a more sophisticated and complex form of organization than linearity in two regards: (I) it integrates multiple rather than single entities, and (2) it is capable of expressing vectorial attributes, and therefore time and motion. Curvature in a temporal environment is the method by which the interaction of multiple forces can be structured, analyzed, and expressed.

The calculation of time as expressed through curvature is possible with calculus, which animates numerical snapshots at an infinite speed, simulating time. Underlying all of the contemporary animation software is a mathematics of the infinitely small interval which simulates actual motion and time through **keyframing.** These transformations can be linearly **morphed** or they can involve nonlinear interactions through **dynamics.** These sequential transformations are possible because the formal entities themselves are described using flexible topological surfaces made of vector splines rather than points.

An example of curvature as a mathematical and intuitive system can be explained by the situation of a FrisbeeTM being chased by a running dog. There are at least three contributing elements to the path of the dog and its possible intersection with the projectile. First, the Frisbee™ has a vec-





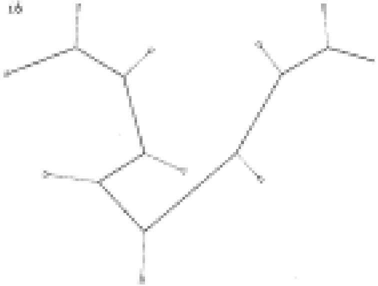
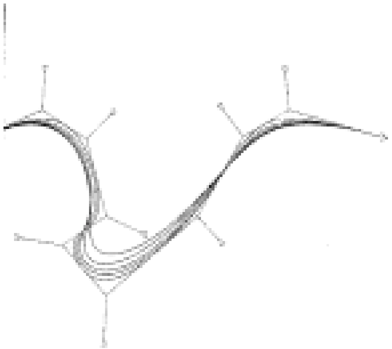


Figure 14: A three-degree spline, where the curvature and inflection is determined by a sequence of positions of three points along the motion flow of the spline.The spline is constructed from control vertices, connected in a sequence, and from which a vector curve hangs with a directional flow.

Figure IS: A seven-degree spline, where the curvature and inflection is determined by a sequence of positions of seven adjacent points along the path of the spline.The seven-degree spline is therefore much smoother than the three-degree spline because it interpolates between a greater number of adjacent points.

Figure 16: A two-degree spline, where the curvature and inflection is determined by a sequence of positions between only two points along the motion flow of the spline.The spline therefore appears to be a poly-line.

for for direction and speed; second, the space in which they move has a wind velocity and direction as well; and third, the FrisbeeTM has a gravitational attraction to the earth. In order to intersect with the FrisbeeTM at a future moment in time, the dog will not follow the projectile but perform a differential equation to calculate both its and the Frisbee'sTM future positions in time as vectors moving toward a moment of possible intersection. The path of the dog will inevitably be described by a curved line.The inflections of this curved line indicate the velocities, directions and timing of each of the imbricated vectors. This situation cannot be described by a straight line with endpoints because, mathematically, it is a differential equation with more than two interacting components. Likewise, any multiplicity such as this will be described by some form of curvature because multiplicities are constructed of interacting entities exerting a differential influence on one another. Curvature is a mode of integrating complex interacting entities into a continuous form. What is important about this example is that initially, the hypothetical dog might be expected to duplicate the trajectory of the FrisbeeTM and therefore it would have difficulty catching the moving object. With practice, the dog might be expected to intuit the patterns of motion of the FrisbeeTM and eventually it will follow a cut-off path in order to intersect with the FrisbeeTM. Although the dog does not actually calculate a differential equation, it perceives the motion patterns of multiple vector fields acting in space and time and can antici-



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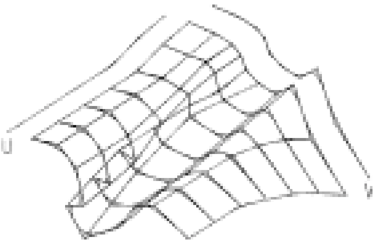

Figure 17: A superimposed series of splines sharing the same control vertices with different degrees of influence; a two-, three-, four-, five-, six-, and seven-degree spline curve.

Figure IB: Two splines showing the distributed effect of a change in one control vertex across the length of the spline.The fourth control vertex is moved and its weight is increased.This change is distributed along the length of the spline rather than only between fixed points.

Figure 19: A spline surface, or mesh, constructed out of groups of splines whose control vertices are connected across one another.The splines are grouped into U and V directions, where the control vertices of the U direction splines pass through the control vertices of the V direction splines.

pate the unfolding of these patterns. By analogy, it is not necessary for architects to perform the differential equations that generate topological forms, as the equation for even the simplest spline is too complex for most architects to calculate. Instead, designers must understand the patterns of topology as they unfold dynamically with varying performance, rather than understanding them merely as shapes.

The shapes that are formed in computer-aided design are the result of decisions made using parameters. Numerical data which describe characteristics of the virtual design environment-such as temperature, gravity, and other forces-have an impact on the forms which result. For example, dynamic modeling systems are based on the interaction of multiple parameter statements calculated sequentially rather than in an instant. Numerical parameters can be keyframed and dynamically linked through **expressions** to alter the shape of objects. In addition to mere changes in shape, these parameters control gradient characteristics of fields such as directional forces, gravities, warps, and particles. Gradient parameters of decay, wave behavior, attraction, and density affect objects as numerical fields of force rather than as object transformations. The linkages between these characteristics of time, topology, and parameters combine to establish the virtual possibilities for designing in an animate rather than static space. Each of these characteristics can be used to rethink the familiar

Cartesian space of neutral equilibrium as a more active space of motion and flow.

The curvilinearity which results from these multiple parameters has previously been simplistically understood as a debased form of linearity, but in fact, it is the ordering of a dynamical system of differential factors. In the early part of this century, Scottish zoolologist Sir D'Arcy Thompson analyzed variations in the morphology of animals using deformable grids, which yielded curvilinear lines due to changes in form (fig. 20). He compared the curvature of deformations in formal configurations to the curvature of statistical data, such as speed, temperature, and weight.Thompson was one of the first scientists to notate **gradient** forces (such as temperature) through **deformation, inflection, and curvature. 17These** three terms all involve the registration of force on form. Rather than thinking of deformation as a subset of the pure, the term deformation can be understood as a system of regulation and order that proceeds through the integration and resolution of multiple interacting forces and fields.

Where Thompson pioneered the analyses of deformation as an index of contextual forces acting on an organism, in the late nineteenth century Etienne-jules Marey pioneered the study of curvature as the notation of both force and time. Francois Dagognet described the project of Marey as

> *. . . showing what one could learn from a curve, which was not merely a simple 'reproduction.' It was from and with the curve that forces could initially be calculated. It was easy to obtain the mass o f the body as well as the speed it was going (chronobiology); from this one could induce the force that had set it in motion, the work expended to produce this action. The trajectory always had to be questioned and interpreted. Not only were the slightest nicks and notches in the line due to certain factors, but they enabled the determination of resistances as well as impulses.18*

Marey was one of the first morphologists to move from the study of form in inert Cartesian space, devoid of force and motion, to the study of rhythms, movements, pulses, and flows and their effects on form.These factors he termed *"motor evidence."* In his book *Animal Mechanism* he shifted his attention from the study of internal pulses and rhythms to the external movements of animals. Unlike Muybridge and others who also employed chronophotography techniques, Marey triggered the exposures with both pneumatic and electrical sensors located on the animals (fig. 21).This, along with his method of attaching tiny reflecting optical disks allowed Marey to sequence the exposures with rhythms of motion (fig. 22). Dagognet describes Marey as pursuing "movements not moments" in his continuous

Figure 20:
Study of the transformation of crustacean carapaces through the deformation of a flexible grid or "rubber mat" by D'Arcy Thompson. From Thompson, On Growth and Form, The Complete Revised Edition (New York: Dover Publications, Inc., 1992), 1057.

Figure 21:
Etienne-Jules Marey used pneumatic triggers, attached to the joints of animals, to trigger camera exposures in rhythmic sequences. In this way, the rhythm of photographic instances were sequenced to the movements of the animal. "Device for harnessing the pigeon to the revolving frame," from Marey, "Le Vol des oiseaux," as appears in Frangois Dagognet, EtienneJules Morey: A Passion for the Trace (New York: Zone Books, I 992), 85.

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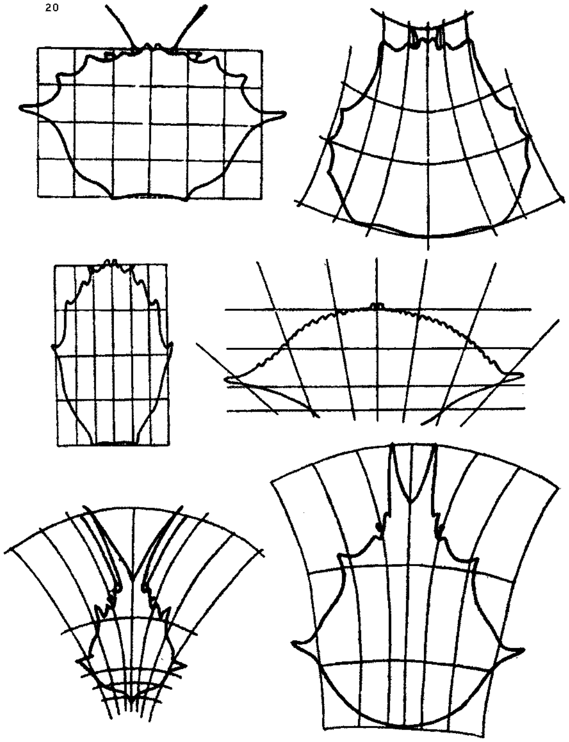

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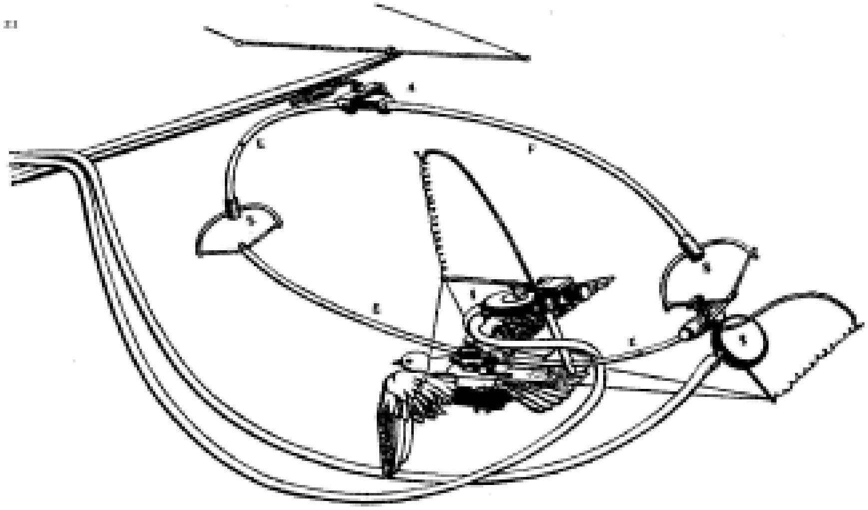


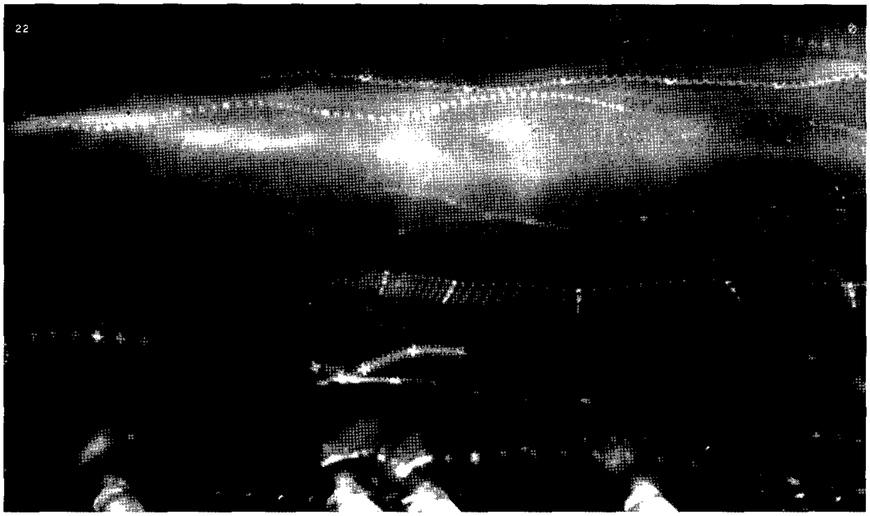


Figure 22: Marey used reflective optical disks attached to key points of the body to capture points of motion. In this example of a horse walking, the film is exposed at a rate where the points begin to blur into motion trails. "Oscillations of the front limb of the horse walking," from Marey, "Le Vol des oiseaux," as appears in Fran~ois Dagognet, *Etienne j*ules Marcy: A Passion (or the Trace (New York: Zone Books, 1992), 75.

data recordings. After exposing rhythmic sequences of images on a single plate, Marey would connect curved lines through these points to describe a continuity across the snapshots (fig. 23). To borrow a term used to describe the behavior of chaotic attractors, Marey produced "phase portraits" by describing time as a continuous curvilinear flow, rather than a divisible sequence reducible to discrete frames. This is the critical difference between Marey's traces of vector movement and the techniques of sequential traces. Marey's model for continuous time based on the inflection and curvature of motion paths and flows, is akin to computer animation.

In addition to these examples of analyzing time, movement, and transformation, another model that has been developed in conjunction with evolutionary theories is the idea of the fitness landscape. With the replacement of fixed types by temporally organized phylogenetic trees, came the model of the developmental landscape to describe the space within which organisms evolve. In mathematics the landscape model has been developed by Rene Thom, in physics by Stuart Kauffman and in developmental biology by Conrad Waddington. It initially appeared when Francis Galton described evolution in terms of a fitness landscape; whereby a surface represents an external environment across which a facetted sphere rolled. The facetted sphere represents an organism with its own internal constraints, and the

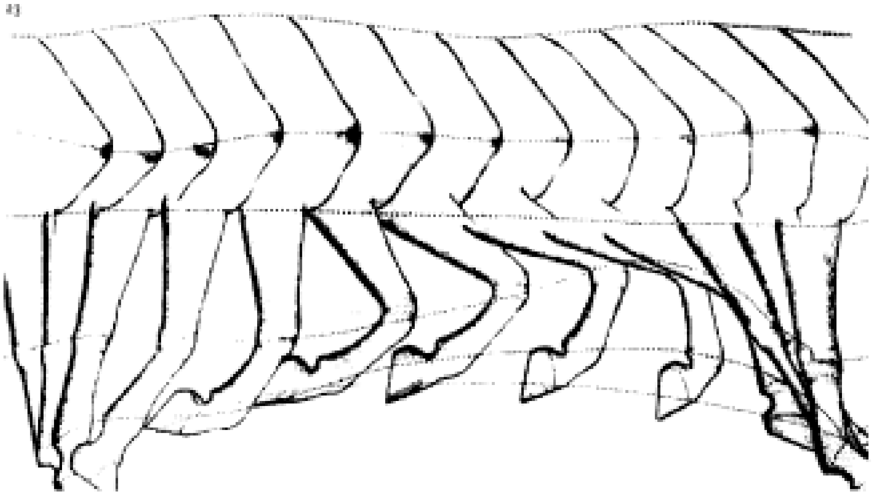


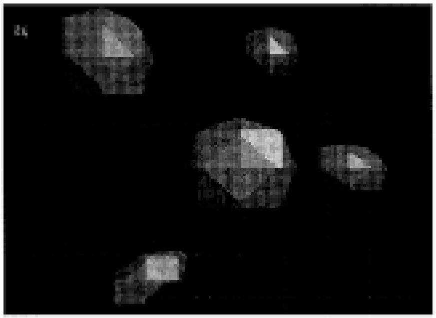
Figure 23: Marey would connect curved lines through these points to describe a curvilinear continuity across the snapshots. "Oscillations of the front limb of the horse galloping;" from Marey, "Le Vol des oiseaux," as appears in Frangois Dagognet, Etienne Jules Marey: A Passion (or the Trace (NewYork: Zone Books, 1992), 75.

landscape represents its potential pathways of development. This concept of a landscape of development informed Charles Darwin’s evolutionary theory of speciation. Similar to any landscape model of organization is an evolutionary or developmental logic.

A landscape is a system where a point change is distributed smoothly across a surface so that its influence cannot be localized at any discrete point. Splines are the constituent element of topological landscapes. Spline surfaces have already been explained as vector sequences whose regions of inflection produce singularities on a continuous surface. The slow undulations that are built into any landscape surface as hills and valleys do not mobilize space through action but instead through implied virtual motion. The movement of a point across a landscape becomes the collaboration of the initial direction, speed, elasticity, density, and friction of the object along with the inflections of the landscape across which it is traveling. The landscape can initiate movements across itself without literally moving. The inflections of a landscape present a context of gradient slopes which are enfolded into its shape. The condition of oriented surfaces has been elaborated by Paul Virilio and Claude Parent in terms of *"oblique"* movement.[19] Likewise, any object moving across a landscape has an initial condition of speed and density that is unfolded across the landscape. This collaboration of enfolding a context and unfolding an object is a temporal, mobile, and combinatorial model for stability and organization. In this schema the object has actual force and motion, where the landscape has virtual force and motion stored in its slopes. The slope of a landscape is a gradient of motion, direction, and time. A landscape also implies a geological time-scale of formation in that although it appears static at any instant, its form is the product of long historical processes of development. This class of landscape objects can be extended to include any form from which temporal development cannot be simply reduced. Topological surfaces that store force in the inflections of their shape behave as landscapes in that the slopes that are generated store energy in the form of oriented rather than neutral surfaces.

The earlier example of the boat hull is itself a micro-landscape for the movements stored in its surface shapes, across which viscous water flows. Similarly the global flows of the water and wind present a macro-landscape for the motion of the boat to flow through. Other topological landscapes include isomorphic polysurfaces (or **blobs), skeletons** (or inverse kinematics networks), **warps, forces, and particles.** Spline entities are intensively influenced by their context due to the fact that they are defined by hanging weights, gravity, and force. For example, the weights and directions pulling on control vertices in space can be affected by gradients of attractive or repulsive force in which the spline is situated. Similarly, the weights of one spline surface can effect those of another spline surface (figs. 24 and 25).These resulting structures are called blobs for their ability to mutually inflect one another and form composite assemblages. The blob is an alternative example of a topological surface exhibiting landscape characteristics although it does not look like a topography. These blob assemblages are neither multiple nor single, neither internally contradictory nor unified. Their complexity involves the fusion of multiple elements into an assemblage that behaves as a singularity while remaining irreducible to any single simple organization. With isomorphic polysurfaces, "meta-clay," "meta-ball," or "blob" models, the geometric objects are defined as monadlike primitives with internal forces of attraction and mass. A blob is defined with a center, a surface area, a mass relative to other objects, and a field of influence. The field of influence defines a relational zone within which the blob will fuse with, or be inflected by, other blobs. When two or more linked blob objects are proximate they will either (I) mutually redefine their respective surfaces based on their particular gravitational properties or (2) actually fuse into one contiguous surface defined by the interactions of their respective centers and zones of inflection and fusion.

Because it is not reducible to any single simple ordering principle, a blob’s fusion and unification are distinct from a discrete totality or whole. In the



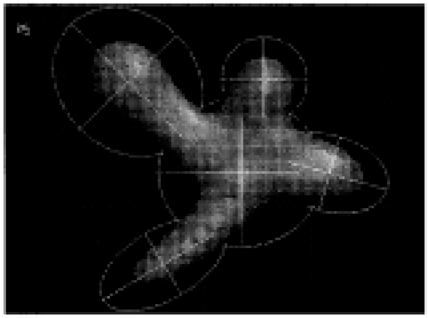


Figure 24: Disconnected primitives used to compose an isomorphic polysurface.

Figure 25: Isomorphic polysurface with primitives fused into a single surface.

case of the isomorphic polysurfaces, either a low number of interacting components or a regular distribution of components will yield a global form that is more or less simple. On the other hand, a high number of components and an irregular distribution of those components yields a global form that is more or less complex.The difference between simple and complex systems is relative to the number of interactions between components. In this schema, there is no essential difference between a more or less spherical formation and a blob. The sphere and its provisional symmetries are merely the index of a rather low level of interactions, while the blob is an index of a high degree of information, where information is equated with difference. Thus, even what seems to be a sphere is actually a blob without influence; an inexact form that merely masquerades as an exact form because it is isolated from adjacent forces. Yet, as a blob, it is capable of fluid and continuous differentiation based on interactions with neighboring forces with which it can be either inflected or fused. In this way, complexity is always present as potential in even the most simple or primitive of forms. Moreover, it is measured by the degrees of both continuity and difference that are copresent at any moment.

Like a natural landscape that stores the history of its geological formation in its shape, these fused topological aggregates manifest their geological conglomeration on a single surface. Time, force, and multiplicity constitute the form of a geological landscape. This structuring of time and energy through curvilinear inflections is characteristic of motion or action geometry. These inflections index both the internal combinations and relationships of elements and their deformation within a larger contextual field. When proposing the model of an internally regulated structure, there are two possibilities: the first approach posits an essential internal order that can be discovered through reductive analysis, the second is a loose binding of constraints that can be realigned and reconfigured in a proliferative and evolutionary manner. In the second category, the internal order is both activated and made legible through the unfolding of its order instigated by external forces. The relationship between a system of internal constraints, such as skeletons (inverse kinematic chains), particles, or blobs and the context in which they unfold is intensive. just as a topological landscape or an assemblage of blobs stores various attractions and combinations in a single surface, so too can topological entities be mutually inflected by the fields in which they are situated. For instance, the space in which a surface or surfaces are located can be assigned with directional force which will inflect the normals of a surface, thus inflecting the shape of the surface based on the relative position to the point from which the force is emanated. The field in which forms are defined is not neutral but can be populated by a variety of interacting forces which establish gradients of influence in a modeling space. Gradient shapes are areas that do not have distinct contours or edges but are instead defined by dissipation from points of emission.These gradients are not measured based on points or coordinates but on fields. Like a temperature map that measures the continuous and gradual change of force across a field, these force gradients do not have edges or contours. The spatial context within which surfaces and splines are conceived then is also animate rather than static.

This possibility of an animate field opens up a more intricate relationship of form and field than has been previously possible. Rather than an entity being shaped only by its own internal definition, these topological surfaces are inflected by the field in which they are modeled. If an entity is moved in space, its shape might change based on the position within gradient space even though the definition of the entity remains constant. Thus, the same entity duplicated identically but in a different gradient space might have a different configuration. A sequence of identical entities located in a series through a gradient space would constitute both a self similarity and a difference based on the characteristics of the gradients and how they were positioned. This relationship between a force and the object which stores that force in its form is reminiscent of the insight made by Henri Bergson in his book, *Matter and Memory,* in which he argues for a nondialectical understanding of the relationship between substance and energy.z0 Bergson argued that matter could not be separated from the historical process of its becoming.

Contemporary theories of organic form, evolution, mutation and vitalism, as defined as the developmental unfolding of a structure in a gradient environment of influences, might be informative to the discussion of topology, time, and parameters as they apply to architectural design. Such discussions of organic processes often involve non-dialectical relationships between matter and information, form and time, and organization and force. This resistance to treat form, time, and motion discretely is equivalent to what might be understood as an organic tradition. The thread of "anorganic vitalism" that runs from Leibniz through Bergson and Gilles Deleuze could underwrite such a discussion, while replacing their natural essentialism with a revised cybernetic concept of the machine as a feedback device that creates hierarchy and organization. One of the best possible models of "anorganic vitalism" is the proposition of "fused assemblages" put forward by Lynne Margulis. The major revision to concepts of holism that Margulis introduces is from a predetermined identity to identities of becoming. Margulis formulated the evolutionary hypothesis that micro-organisms evolve their complexity by incorporating simpler organisms into larger multiplicities that become capable of reproduction as a singularity.z1 Thus, organisms are seen as previously free living colonies of organs that become a fused singularity. In her schema, there is little difference between a single body and an ecology of organisms, as both exploit one another’s functions and machinic behaviors through feedback and exchange. A body, Margulis suggests, is the fused assemblage of an ecosystem operating with a high degree of continuity and stability.There is no essential structure to such an assemblage that one can uncover or deduce, at either the macro or micro scale. It is a logic of differentiation, exchange, and assemblage within an environment of gradient influences. The form, or shape, most often cited in reference to such an environment is that of the landscape. The epigenetic landscape is a theoretical and analytic device used to describe the relationship between an evolving form, or organism, within its developmental field, or environment.

Producing a geometric form from a differential equation is problematic without a differential approach to series and repetition. There are two kinds of series: a discrete, or repetitive series and a continuous, or iterative series. In a continuous or iterative series, the difference between each object in the sequence is critical and individual to each repetition. If the difference is the product of three or more variables, and if those three variables are unrelated, then the change between each iteration will be nonlinear in its structure and it will therefore be difficult to predict with absolute precision. Each step is thus dependent on the precise position of each of three or more variables; meaning that the future position of the iterative series cannot be calculated outside of the series itself. In an incremental, discrete series, the differences that accompany each repetition are linear and reducible.The entire infinite set of possible futures of the series can be calculated in advance with a simple mathematical equation. In the case of the continuous series such exact definitions are impossible to determine at the beginning, as the beginning is not an origin but merely a point of departure. The future possible positions of a continuous series must be thought of as a continuum rather than as an enclosed infinity. This points to the important distinction between the infinite and the continuous, two terms which are often casually conflated. Difference and repetition, when thought of in a continuous rather than discrete manner, mandate a thinking in duration rather than in points.

This difference is crucial to an understanding of the spatial difference between the infinite and the continuous. A continuous series can be "infinitized," or reduced, through "iterative reduction," leaving a single, ideal type. In this method, a limited set of variation is organized in a series so that its continuous differences can be progressively eliminated, leaving a discrete type that can then be infinitely extended. This method of iterative reduction can be attributed to Edmund Husserl, as it is central to his invention of phenomenology.

Motion and time are similarly taken away then added back to architecture. Architectural space is infinitized by removing motion and time through iterative reduction. They are then added back typically through phenomenology. The dynamic concept of architecture, however, assumes that in any form there are inflections that direct motion and provoke and influence the forces moving through, over, under and around surfaces. The form is the site for the calculation of multiple forces. This is the case in the example of the sailboat, where on the hull's surface multiple points of sail are calculated and resolved in the form itself. The perception of the hull does not require the resolution of multiple vectors of movement as those vectors are stored in the object itself as potential energy or flow within a gradient field of forces. Moreover, the primary method of experiencing these vector effects is not optical or through aesthetic contemplation but instead through performance. The vector flows that are calculated and stored in the shape of the hull can be unfolded through both aesthetic analyses and use. Perhaps the best precedent for the unfolding of curved space is evident in the concept of Frederick Keisler's "endlessness" along with Adolf Loos's concept of the "raumplan" from which it was derived while Kiesler was working in Loos's office.22 Although a discussion of the counter tradition of modern endless space versus the canonical modern tradition of infinite space is not possible here, the difference from the more classical and reductive models of modern form should be recognized.

The best model for the discussion of non-reducible forms of motion might be to return to the model of the landscape or the oblique ground, where motion is stored in the gradient slopes of a surface across which an object moves. Here the potential motion of an object across a surface is stored in a virtual manner as future potential energy. To return to the force discussions, the influence of a gradient space of force and energy is built into the spline networks through the inflection of their normals. A landscape is a ground that has been inflected by the historical flows of energy and movement across its surface. These historical forces manifest a geological form of development that is inflected and shaped by the flows that have moved across it. These slow transformational processes result in forms which are oriented with motion, both the virtual motion of their history and the actual motion they initiate through their slopes and valleys. This animation of slow form with the historical processes of gradual geological becoming is a paradigm of motion and time that renders substance virtually animated and actually stable. Rhythmic motion is manifest in stable-oriented form rather than in literally moving objects. In the words of Hans jenny,

> . . . Nature reveals an abundance of sculptured forms, and all of them, it must be remembered, are the result of vibration. If the tome ceases, the mass ‘freezes.’ Looking at these vibrational effects, it would be no exaggeration to speak of a true magnetocymatics with its own dynamokinetic morphology. Experiments like this based on pure empiricism stimulate the plastic imagination and develop the power to feel oneself into a space permeated by forces.23

The work of Hans jenny in the 1950s and 1960s is undoubtably the best example of the study of how oscillating, fluctuating, gradient fields of forces can produce not only patterns but forms. The primary theme that runs through jenny’s writings about these experiments is the continuous character between the forms produced and the fields from which they emerged. For example, jenny argues that in the case of "the vibrational feld it can be shown that every part is, in the true sense, implicated in the whole."24 His experiments consisted of the effects of vibrations on a particulate concrete medium. The concrete forms he studied were in an environment where vibration and wave phenomenon were inherent to the system of form generation and evolution. He gave these structures the name "cymatics" meaning the "characteristic phenomenology of vibrational effects and wave phenomenon with typical structural patterns and dynamics."25 In general, jenny pioneered the use of viscous particle flows on plates that were both vibrating and magnetized. His techniques varied from the study of iron fillings on

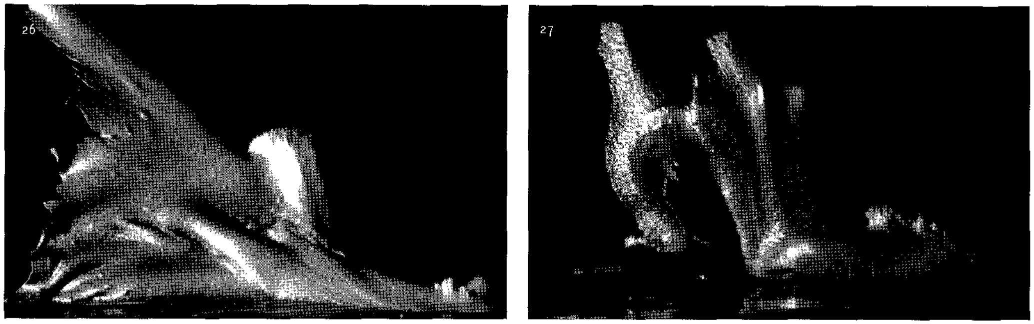
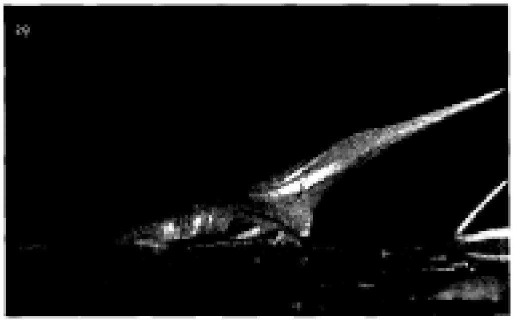


Figure 26 and 27: A sequence of flowable mass through a vibrational magnetic field by Hans Jenny. "These figures show the plastic pattern of movements displayed by a ferromagnetic mass in a magnetic field under the influence of vibrations. The mass flows in the magnetic space and reflects its configurations. It writhes, rears up, and stretches out but always in a way that reflects the situation in the magnetic field at that particular time;" From jenny, vol 2 of Cymatics:Wave Phenomenon Vibrational Effects Harmonic Oscillations with their Structure, Kinetics and Dynamics, (Basel: Basilius Press, 1974), 62.

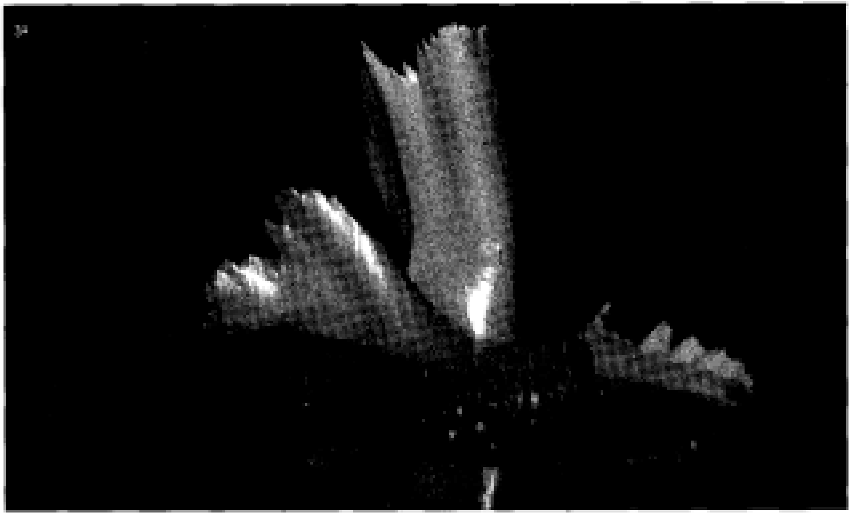
Figures 28 and 29: Jenny's description of the formation of these forms in magnetic space takes the language of architectural structure as he mentions both arches and walls. "Under other conditions there are upfoldings which rise up to form arches. These structures tower up and tend to flow along a path. Then they thrust out again into space, and in the interplay between the cohesion of the mass and the magnetic force they spread, grow thin, and peter out. Forms tower up displaying the configuration wrought by magnetic force and oscillation. Large leaflike walls take shape and sway to and fro in the magnetic field." Jenny. Cymatics, 61.

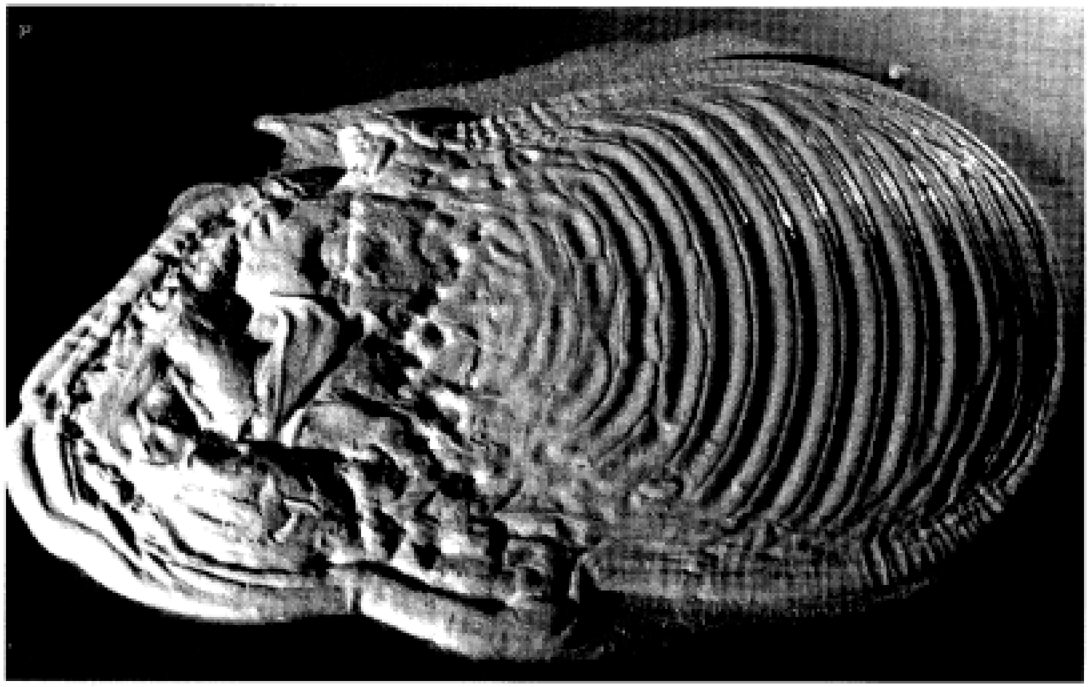
plates to the sandwiching of fluids between vibrating glass plates. jenny also used motion pictures to capture the movement of these forms within the magnetic pathways of oscillating fields. His method was to study the motion sequences of the forms rather than their static form. Previously, particles of filings and other materials were treated as discrete elements that would form a pattern that was coincident with the geometry of the plate. By introducing viscosity to the particles thus forming a continuous semi-solid flow, Jenny was able to study the shaping of form in free space rather than in two-dimensional pattern only. By varying the Reynolds numbers of these particles suspended in a fluid, he was able to develop an intuition into the morphology of forms within magnetic fields. His studies involved the familiar use of a vibrating plate that would configure iron filings into patterns. Added to this influence was the presence of magnetic fields to impose polar patterns on the filings. These forces were then thought of in terms of periodic excitement by both the vibration oscillation and the changing position of the magnet. Thus the forms that emerged were studied both in their form and in the ways in which they would follow the magnetic pathways. The play between two types of fields, magnetic and vibrational, produced form. The character of these forms were persistence and continuity, but, unlike discrete reducible forms, they remained continuous with the fields within which they were generated. Rather than making shapes through the familiar operations of a sculptor or architect, through direct manipulation



Figures 30 and 31:
"These masses have solidified under vibration. The relief is complicated in structure because each of the various stages of consistency the mass has passed through while solidifying has left its imprint. There are large billow-like formations and tiny wrinkles, wave trains succeeding one another, and sudden changes in the direction of flow. It is as if the 'history' of the process had been recorded in transverse and longitudinal folds. There is also a tendency for a latticework of folds to take shape:" Jenny, Cymatics, 63.

Figures 32 and 33 (next page): "A flowoble mass assumes a characteristic pattern under the influence of a high-frequency tone. Trains of waves take shape. The substance forms into a lump which, because adhesion is reduced, glides round in one piece. The substance forms bays and promontories, spreads out thinly and is then thrown into folds which make a rugged relief" Jenny, Cymatics, **IS-19.**

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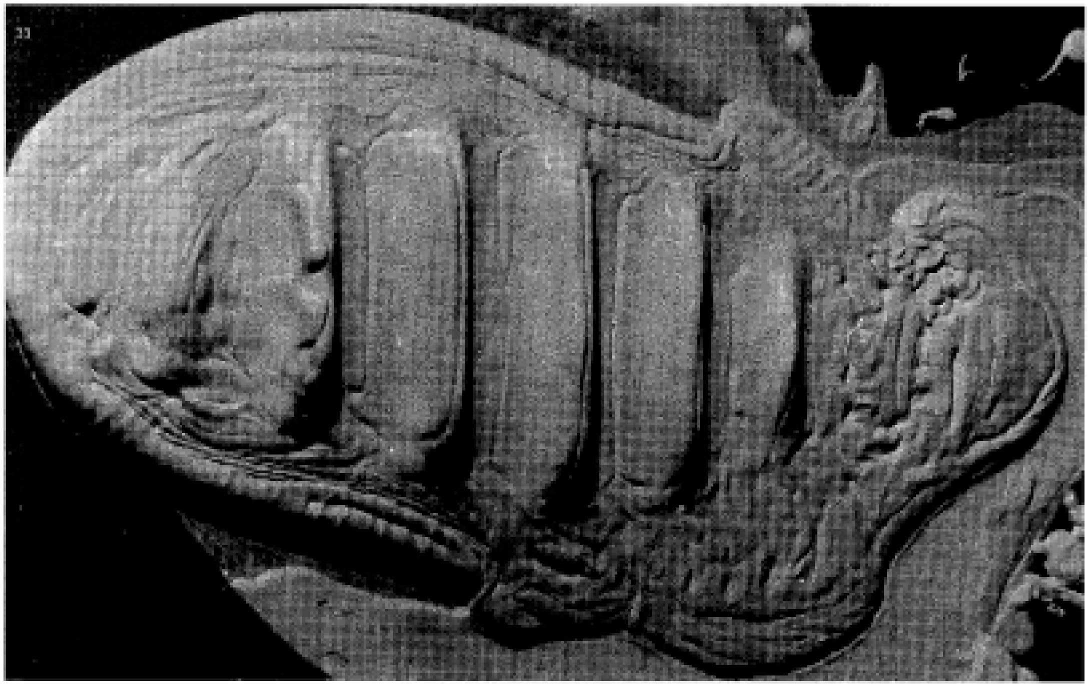

of material for example, jenny modulated form through oscillating frequencies and parameters. jenny sculpted form through the adjustment of oscillators without forfeiting his intuition to a machine intelligence. The shift from sculptural techniques of whittling, carving, chipping, and scraping material to the modulation, oscillation, and vibration of particles does not mandate the relinquishment of creativity to machinery. Instead, it suggests the creative manipulation of a flow of parameters in time.

The use of parameters and statistics for the design of form requires a more abstract, and often less representational origin for design. The shape of statistics, or parameters, may yield a culturally symbolic form, yet at the beginning, their role is more inchoate. A return to the discussion of the orrery might supply two terms: the "concrete assemblage" and the "abstract machine." For example, in ttienne-Louis Boullee's Cenotaph to Newton, the orrery operates as both an abstract model and as a sign. The orrery, in the sense that it represents the movements and organization of a centered and harmonically regulated universe, is a concrete assemblage. To the degree that it is a diagram for centralized harmonic regulation, like a compass, it is an abstract machine. The diagram for the orrery can be seen to circulate among many institutional and symbolic regimes where it takes on many meanings. As a statement of centralized regulation, however, its abstract performance is consistent. Any abstract machine, such as an orrery, can be understood as both a technical statement and as a signifier. Neither its representational nor its technical structure can be understood independently. The difference between its abstract and representational roles can be located precisely at the moment it crosses the technological threshold from being a diagram to a concrete assemblage. The use of the term abstraction here is not intended to be confused with the purist or modern notion of visual abstraction. In those instances abstraction involves an aesthetic reduction to fixed formal essences through the paring away of differences. An alternative concept of abstraction, one that is more generative and evolutionary, involves proliferation, expansion and unfolding.This marks a shift from a modernist notion of abstraction based on form and vision to an abstraction based on process and movement. In order to define such a diagrammatic regime, it is perhaps most helpful to cite Michel Foucault's terms; "abstract machine" and "diagram." Gilles Deleuze has referred to these terms as "asignifying concepts." By definition, an asignifying concept is instrumental before it is representational. This model depends on the precise distinction between "linguistic constructions" and "statements." Linguistic constructions, such as propositions or phrases, can always be attributed to particular referents. Statements, on the other hand, are not initially linguistic but are machinic processes.26 For instance, the sequence of letters Q, W, E, R,T,Y is distributed on a typewriter or computer keyboard to produce words. The logic of their sequential distribution is based on the control of the speed at which one can potentially type words in the English language.There is no single sentence or word that tests this distribution but rather an indefinite series of existing and future words. Because there is an open series the system must be characterized as indefinitely structured. The keyboard is an actual machine, or concrete assemblage, because it is technological. But the distribution of its letters on keys in space is a virtual diagram, or an abstract machine. Statements such as these are machinic techniques, discursive concepts, or schemata that precede the representational and linguistic effects they facilitate. Signifiers are not rejected but delayed toward the moment that they are *"found at the intersection o f different systems and are cut across by the statement acting in the role of primitive function."27* Linguistic constructions are merely postponed, not abolished, and a regime of abstract, schematic statements are seen to preempt and sponsor them. From the particular discursive formation of multiple, diagonally intersecting statements, some form of expression emerges. Through the interaction of a multiplicity of abstract statements, signifiers emerge in a more dynamic manner than mere representational effects might. The shift from linguistic models to the proliferation of asignifying statements marks what Deleuze terms a move from the *"archive"* to the *"diagram."2$* The move from linguistic constructions to statements, or more properly from meaning to machine, is a necessary shift in sensibility if one is to tap the potential of abstract machines such as computational motion geometry and time-based, dynamic force simulations.

This shift is the primary explanation for the apparent alliance between certain aspects of Deleuze and Foucault's discourse and many contemporary architects now weary of representational critiques spanning from stylistic postmodernism to deconstruction. In Deleuze's interpretation of Foucault's critique of panopticism, concrete architectural form is transformed into abstract machinic instrumentality. Techniques, as opposed to technology, become an expression of cultural, social, and political relations rather than as an essential power. The effects of abstract machines trigger the formation of concrete assemblages when their virtual diagrammatic relationships are actualized as a technical possibility. Concrete assemblages are realized only when a new diagram can make them cross the technical threshold. It is the already social diagrams that select the new technologies. It is in the spirit of the abstract technical statement yet to become concrete that topologies, animation and parameter-based modeling are being explored here. In order to bring these technologies into a discipline that is defined as the site of translation from the virtual into the concrete, it is necessary that we first interrogate their abstract structure. Without a detailed understanding of their performance as diagrams and organizational techniques it is impossible to begin a discussion of their translation into architectural form.The availability and rapid colonization of architectural design by computer-aided techniques presents the discipline with yet another opportunity to both retool and rethink itself as it did with the advent of stereometric projection and perspective. If there is a single concept that must be engaged due to the proliferation of topological shapes and computer-aided tools, it is that in their structure as abstract machines, these technologies are animate.