The Autonomous Nature of Creativity in Juxtaposition to the New Structuralism

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Creativity is independent of technology; it lies in the mind of the designer and may be either augmented or hindered by the capabilities and limitations of digital software. For the purpose of argument, this paper will limit itself to the creation of complex form. Fifty years ago complex forms involving double curvatures were accomplished without the use of digital technology and through the same basic strategies used today. The only difference is, since the digital revolution of the 1990s, software allows the designer to create form through the application of rules or parameters rather than conceiving form wholly through inspiration, tradition and the vernacular.

If creativity is autonomous, then digital technology is merely a tool and not a driver of design. If not, creativity may be directed or dictated by the limits of software. The term *New Structuralism* implies a return to rules, a process- driven design methodology fully entwined with research of project parameters and materiality. Rivka Oxman states, "The New Structuralism presents a body of novel representational and process models in which form, structure and material are integrated as one entity in a single model of design"[16]. The disposition of creative autonomy with regard to form, structure, and material can best be assessed when compared to the creation of complex form in pre-digital design.

COMPLEX FORM IN PRE-DIGITAL ARCHITECTURE

When Eero Saarinen was commissioned for the design of the TWA Terminal at Idlewild Airport (now

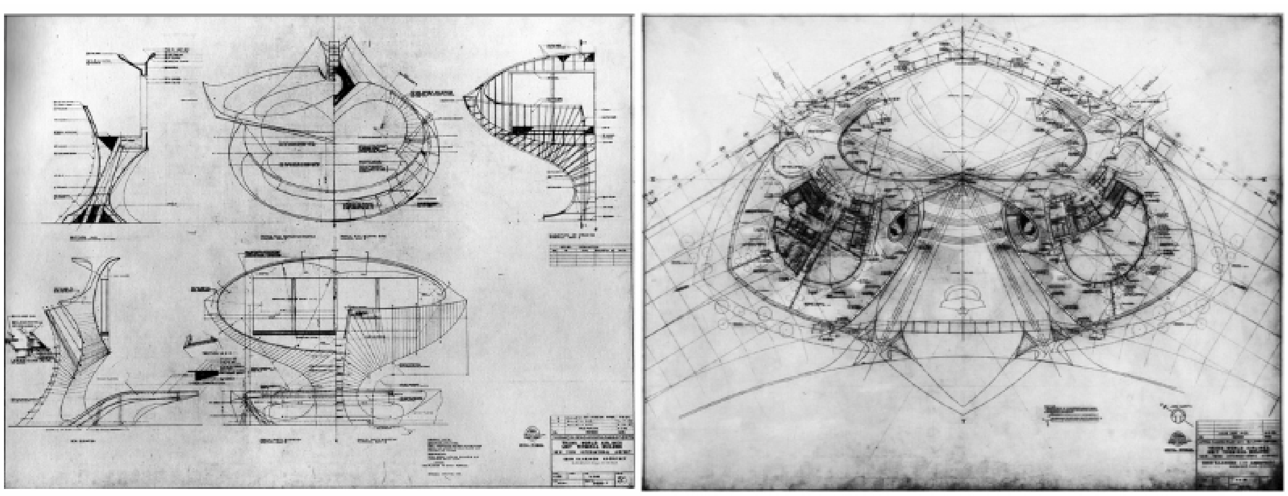

Figure 1. Source: Antonio Roman, Eero Saarinen: An Architecture of Multiplicity, New York: Princeton Architectural Press, 2003.

JFK) in 1956 he was given the directive to capture "the spirit of flight"[1]. In many ways the building resembles a bird in flight, but more so, it inspired a nation of new air travelers to believe they had finally reached the space age.

Architectural Forum attested to this fact by stating that the terminal was a "smooth and luxurious switch from ground transportation to planes" and that "the birdlike form is not mere caprice or design virtuosity."[2] Although the inspiration may have been avian, the shell shapes originated by observing the compression of grapefruit rinds[3]. Cardboard and wire models followed assuming the shapes of mushroom caps bisected and rearranged until the final configuration of four rounded diamonds evolved[4].

This procedure is typical of pre-digital design: the physical modeling of a form precedes the drawing of the shape. Saarinen's team actually created a full-scale mock-up of the interior in cardboard[5]. The architects developed 130 drawings of sections and details with the help of engineers Ammann & Whitney[6]. These drawings were used to develop the scaffolding using over 2500 plywood wedge shapes of twenty-seven different shapes. What Saarinen has taught us, despite the harsh criticism of an Architectural Review article in November 1962 (thankfully after Saarinen's death) which likened its wonderful flow of space to a rat-maze without the credibility of first-hand experience, is that creativity in creating complex form is not dependent on digital technology.

At the same time, Felix Candela experimented with the hy-par (hyperbolic parabaloid) and created the conch shell roof of Los Manatiales Restaurant. A more regular geometric form, its 4cm thick shell carries design loads with a maximum compressive stress of only 186psi[7]. A decade earlier Pier Nervi combined two simple ideas of support: corrugation and arches to create the Torino Esposizioni complex allowing natural light through the ninety-five meter span[8]. Both of these examples used regular geometries with easily defined sections. The solutions are both elegant and easily drawn and along with Saarinen's TWA Terminal, all three realized their original vision. But it must also be realized that not all creative form has been built exactly as envisioned.

In January 1957, John Utzon was announced as the winner of a competition to design a performing arts space on a wharf site in Sydney, Australia. Utzon's competition entry, inspired by the sails of yachts in the harbor, consisted of double curvature shells. When the structural design became problematic due to the irregular curvatures, Ove Arup, the engineer for the project, and Utzon worked through a number of parabolic, ellipsoid and spherical schemes for simplifying the shells into a buildable form. Four years later, Utzon suggested changing the shell shapes to a wedge shape cut from a sphere[9] so that the curvature would be the same in both directions.

Despite protests from Utzon that the design was not complete, construction began in March of 1959 and proceeded slowly for fourteen years. The shells were supported by pre-stressed concrete ribs covered with precast concrete tiles. But the process at first was much too slow and it was quickly realized that a faster method of locating the precise placement of structural members must be found in order for the opera house to be completed.

> "Metal pins were inserted into the concrete units in known locations; once erected the positions of the pins were checked with theodolite. These survey readings would be dispatched by taxi to Australian General Electric's computer in York Street, Sydney, fed into the program and run overnight." [10]

The computer assistance aided the construction process only. Fortran, a computer language invented in 1954 could have aided the design of the components through a purely mathematical point of view. But designers are visual thinkers, and did not readily embrace computer software until the availability of Computer-Aided Design programs in the 1980's. If designed today, the shells could have remained true to Utzon's original scheme. However, it would be subjective to ponder whether the original sketch forms would have proven the better solution.

What Santiago Calatrava shares with Candela, Nervi, Saarinen and Utzon is a predisposition to design in three dimensional space using sketching, followed by physical modeling. In 1981, Calatrava presented his Doctorate dissertation: On the Foldability of Spaceframes.[11] This work launched his career toward the creation of expressive, dynamic structures. Calatrava's process is pre-digital: he uses rods and connections, physically modeled to realize his original hand-drawn concepts. This method persisted even in the mid-nineties with the design of the addition to the Milwaukee Art Museum. Hand sketches were followed by physical modeling despite the availability of three-dimensional modeling software. And while his designs are intricate, the members are linear, vector active, epitomizing the notion of the pregnant pause, Calatrava's structures are in fact dynamic and conceived without digital design.

THE DIGITAL REVOLUTION

With the development of Adobe Photoshop in 1989 and 3D Studio by Autodesk in 1990, visual digital representation in architecture began to follow the advances already made in film making. Architects began to use 3D software to create space, but were limited to simple geometric forms that could be scaled, repeated, rotated and mirrored. As designers employed these tools, logical patterning began to return to design thinking coupled with an appreciation of mathematics. The ability to array and tessellate with varying scales, often employing fractal mathematics led designers to begin exploring basic concepts with digital expressions. It is probably no coincidence that the prevalence of deconstructionism in architecture coincides with the development of computer-aided drafting. CATIA was developed by Dassault Systemes beginning in 1977 for aircraft design. Engineers in Arup and SOM began using the software and by the mid-1990s architects followed suit. Catia allowed structural analysis of design ideas, making the feasibility and fabrication of complex form affordable by saving countless engineering hours. The next leap in digital thinking occurred when Autodesk Maya, and its competitor Rhinoceros, introduced digital designers to NURBS (Non-Uniform Rational B-Splines) in 1998. NURBS allow a designer to create smooth curvilinear surfaces. The free student licenses offered by Autodesk and the affordable prices to students offered by Rhinoceros have given them a clear footing in design resulting from the fact that graduating architecture students tend to use in practice software they have learned in school. With Mel Scripting and Grasshopper, designers have easily transitioned to parametric modeling, and as a result returned to a rule-based design thinking dubbed the New Structuralism.

Digital software gives architects an opportunity to virtually explore spaces in three dimensions, but few examples exist outside of academia until the late 1990s. Foster + Partners embraced 3D modeling and used it extensively in projects with double curvature such as The Swiss RE Building 1997, Albion Riverside and City Hall 1998, both in London, and Gateshead Regional Music Centre 1998. The Swiss RE Building is a diagrid structure inspired by Silica Sea Sponge. Branko Kolarevic, Mark Burry, Peter Wood and Keith Ball "developed an 'elastic' modeling program for creating variable forms of 'egginess'"[12]. ARUP Engineers developed the GSA software program for structural analysis of the diagrid. This structure could easily be conceived without digital tools by creating simple section drawings, but it is significant because the digital exercise illuminated the possibilities to the designers.

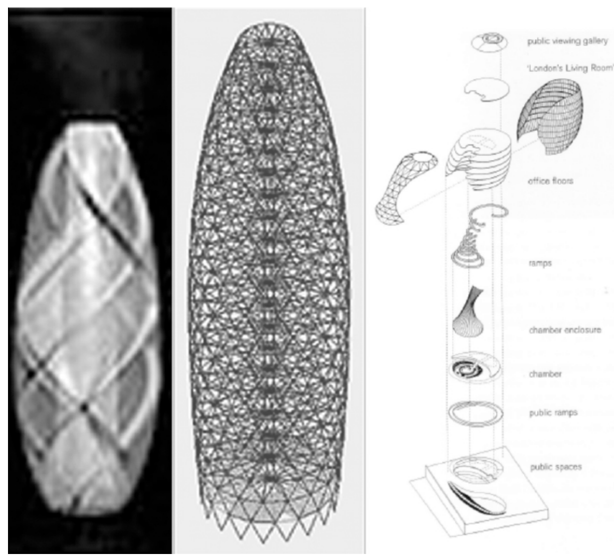

Figure 2. Swiss RE BLDG: Parametric models, GSA Structural Model. London City Hall geometric diagrams. Source: , Foster and Partners, ARUP, James Steele, Architecture and Computers, New York: Watson-Guptill 2001, p.98

A mere year later, the complexity of parametric modeling in the London City Hall (Greater London Authority) results in an asymmetrical environmentally-responsive form developed by the layering of core, tiers and shell in a complex pattern of shapes that in retrospect shows both a fascination with the novelty of the software at hand and a mastery of digital design thinking. The shape maximizes shading and minimizes direct sunlight exposure on the envelope, a sustainable solution that creates both schematic challenges and formal opportunities. Earlier projects such as University of Cambridge, Faculty of Law in 1990 had utilized a single-curvature diagrid structure. Both of these projects are significant examples in that they unify form with structure and material while realizing curvature about two axes.

In 1993 UN Studio created Möbius House[13] based on the idea of the double-locked torus. The physical shape of the residence does not literally embody the smooth curve of the torus, but uses it as a concept. The patterns of circulation follow the Möbius strip smoothly through the living/working/sleeping cycles of the user, but that smoothness of transition of place is not translated to the physical realm of non-orthogonal planes. Three years later, UN Studio used a Klein bottle as a concept for the Arnhem Transfer Hall. As in Möbius House, the concept shape defined circulation. By unlike Möbius House, the concept form begins to appear as physical form as well. The complex curves were digital generated and rendered. This formal expression of concept was not new in 1996, but the ability to achieve it in digital media was a clear step toward future projects such as the Burnham Pavilion in 2009. There is a natural mathematical progression from a Möbius strip to a Klein bottle to a trefoil; the last being the concept behind the Mercedes-Benz Museum in Stuttgart[14] in 2001. The museum is a structure more closely resembling the concept idea than either Möbius House or the Arnhem Transfer Hall, and yet, like the two previous projects, the concept for the Mercedes-Benz Museum is based on a circulation pattern. It is the need to understand the complex circulation pattern that drives both the structural and spatial forms for the museum. The progressively tighter application of specific geometric rules to define circulation in the three UN Studio projects is indicative of the influence of digital technology on rule-based design.

NOX Architecture and design firm was a significant leader in digital, process-driven development of research such as Foam Home conducted in 1997[15]. The diagram at left below clearly shows the rule-driven progression from an orthogonal grid to a foam brain-shaped enclosure. Such parametric investigations were the beginning of what Helen Castle of *Architectural Design* calls "The New Structuralism"[16]. Form and structure are united; inseparable. But NOX Architecture used analog and digital methods together in to develop of projects in the early 1990's. Nox Architecture focuses on the relationship between movement and architecture; a seeming duality that works well with the digital tools of splitting, bending and twisting. In 1993,

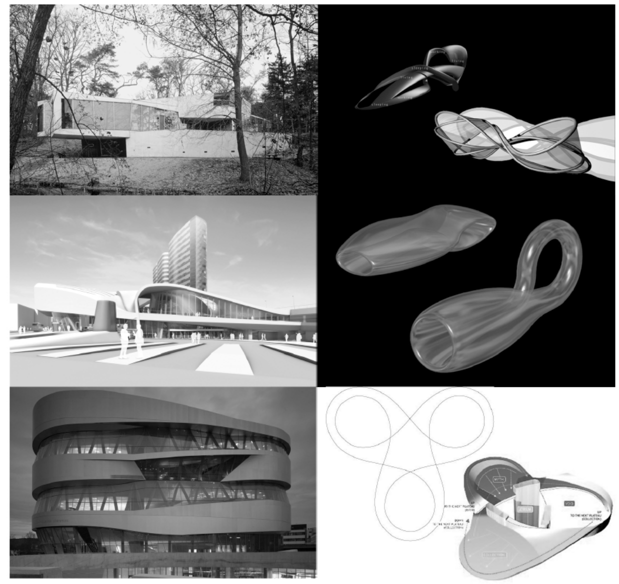

Figure 3. Mobius House, Arnhem Transfer Hall, Mercedes Benz Museum Source: www.unstudio.com/projects

NOX began with a linear set of ellipses to develop the exhibit form for H_2O expo at "Waterland" in the Netherlands. When drawing the form in AutoCad 11, they were limited to using segments of circles

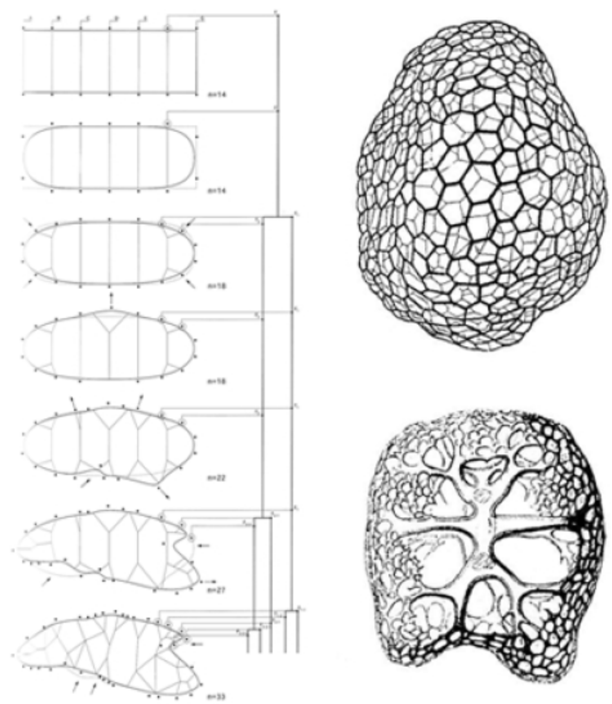

Figure 4. Lars Spuybroek, NOX: Machining Architecture, New York: Thames & Hudson 2004

to approximate ellipses. This is a case where technology still did not meet the creative vision of the designer, although NOX found that it was a fortunate compromise because the fabrication process was based on circles as well.

Toyo Ito used single curvature roof elements in 1991 with a vector active roof in Gallery U in Yugawara and in the Yatsushiro Municipal Museum[20]. But it is the Shimosuwa Municipal Museum, designed in the same time period, that exemplifies his interest in digital design. The building involves complex curvature with a faceted skin, the exactness of which would require site fabrication in a pre-digital design. The Odate Dome in 1993 created a rippled translucent shell. These works by Ito were no doubt stepping stones in the digital thinking that led to the design of Meiso No Mori Funeral Hall in Kakamigahara, Japan by Toyo Ito, 2004. The Hall perhaps best embodies the spirit of Saarinen's free form concrete shell. "Ito's work is underpinned by two principles: fluid spaces that give a tangible sense of dynamic force, and spaces that recall organic forms"[19]

> "Close collaboration between architect and engineering generates structural and spatial innovation. Creative ideas can be turned into reality using complex geometries and advanced software… Sasaki introduces the concept of 'extended evolutionary structural optimization'. By applying the principles of evolution and 'self-organization' of living organisms to an engineering problem; rational computer-generated structural forms can be generated." [19]

Ito recognized in 1995 the change that digital technology had already heaped on the world when he stated,

> "...we have transformed ourselves so that we could reverse the poles of reality and unreality by the simple manipulation of an image. The progress of media has resulted in the isolation of words from products, diluting the reality of the products themselves."[20]

And yet, Ito's work does not choose to dilute reality, but rather to compliment it. The influence of digital technology is clear in the Fukuoka Prefecture 2002[21], where the undulating green roofs of the project seem an earthy variation of the hovering cloud effect of Meiso No Mori. It should be noted that although much of the complex curvature resulting from digital technology involves new materials; concrete shells had been wholly abandoned since the early sixties. Examples such as Heinz Isler's BP Petrol Station in Deitingen[22], 1968 can attest to an ongoing interest, but the geometry is simple despite its elegance. Digital drawing has spurred digital fabrication, making complex curvature more affordable. George Vrachliotis spoke of implications for the future:

> "One thing is clear: the deployment of computers serves to increase the complexity of built geometries to an extent that their cost-effective implementation will be realized only by digital means. This will certainly lead to different but not necessarily better architecture."[23]

THE VOICES OF CONCERN

Perez-Gomez and Pelletier stated that digital technology is,

> "the culmination of the objectifying mentality of modernity and it is, therefore, inherently perspectival. Indeed, the invisible perspectival hinge operating in nineteenth-century axonometric space is internalized and made even more 'natural' by computer technology, resulting in a powerful tool of reduction and control. The tyranny of computer-aided design and its graphic systems can be awesome: because its rigorous mathematical base is unshakable, it rigidly establishes a homogeneous space and is inherently unable to combine different structures of reference."[24]

Exactly the opposite can and has occurred, as discussed earlier. Digital Design allows exploration into the dynamic relationships at the envelope; the duality of inside working with outside. The perspectival hinge is not internalized, but reconfigured. Spaces developed are not homogenous or rigidly established. The deformation of space allows the designer to manipulate the environment and, as a result, the user experience.

It must be recognized that the rate of change in Architectural Design due to digital technology threatens the vernacular. Kenneth Frampton reflects that,

> "despite the advances of technoscience …one remains apprehensive about the tendency of technology to become a new nature covering the entire globe. Against this tendency, the phenomenon of uneven development is a redeeming influence in that building, like agriculture, tends to be grounded in time-honored processes that are essentially anachronistic. At the same time one has nonetheless to recognize the critical impact that countless technical innovations have had upon the character of the built environment."[25]

A viewing of any urban timeline will attest to the fact that the vernacular is dynamic and because media technology is speeding up globalization, there is a global architecture evolving. Every vernacular has at some scale political, immigration, or trade influences; and now digital influences introduce another dimension of change.

The Miesian mantra of Form Follows Function seems outwardly to be lost when considering complex forms; as Saarinen critic Scully had proclaimed fifty years earlier. The revival of complex form in architecture during the digital revolution suggests technology either inspires or dictates form based on the digital aptitude of the designer. Maya, Rhino, Catia and the like, all allow the creator to freely sculpt form or to apply defined rules derived from conceptual relationship. The rules generate formal ideas but only to the extent of software capabilities to create form or the ability of the designer to understand the software. Without full software mastery, digital designers often compromise the original vision to fit their virtual skills. With full knowledge of the limits of the software available, digital design becomes inspired. Designers with little structural knowledge but strong digital form-generating skills may create forms that reveal structural issues. Few form-generating programs are equipped to analyze shapes for structural loads. Regardless, software's ability to help the designer create structural patterns in the conceptual phase of design far outweighs any problems that may be wrought upon the engineer. Because structural patterns are mathematical forms by nature, the digital forms generated tend to follow a structural logic to some point. When past the point of reason, it is up to the designer to redesign or seek out new technology to support the form. When technology drives design, design in turn drives technology. The fact that good design is relative to the ability of the designer to use the tools at hand is irrelevant to whether the design is digital or analog. But the ability of a designer well skilled in both analog and digital tools will benefit creatively from digital technology.

The complex forms of the nineties differentiate themselves from those of the fifties in that they allow the generation of form to reveal its parametric patterns through the envelope. This is a significant change in that the envelope is no longer a façade but integrally tied to the structural patterning and the project concept. Patrick Schumacher states, "Articulatory strategies have to be devised that order the visual field and guide the eye to recognize abstract configurations and the focal moments or key distinctions within them."[17] It is the variation in parametric process that expresses the detail through change in scale or shape, thus articulating an idea of entry, flow, hesitation, solitude and the like. Schumaker's concerns about articulation of focal moments are justified and perhaps due in part to the loss of scale while working digitally on a screen. Articulation of a focal point is dependent on scale and material. Antoine Picon's essay *From Tectonic to Ornament: Towards a Different Materiality*[30] deals more specifically with issues of the loss of a sense of scale and the redefinition of materiality. Scale is problematic in that it is relative to contextual adjacencies. The ability to zoom in and out of the virtually created environment overrides the innate sense of scale born to most designers. But the more interesting quandary is the notion of a shifting idea of materiality from one derived by nature and physical laws of the world to one that is "marked by a proliferation of ambiguous hybrids of nature and technology."[30] If materiality is defined through our physical and cultural views of the world, then the virtual world will also shape our experiences and affect our sense of materiality. The concerns of scale and material articulation are once again concerns about the ability of the designer to use digital technology.

Given adequacy with digital tools, the question remains as to whether designers design complex curvature differently with digital technology than with analog tools. Wolf Mangelsdorf speaks of four strategies used in the design of complex forms, the first of which is form-finding. "Form finding refers to the design of engineered minimal surfaces – doubly curved tension or compression structures – based on physical constraints."[16] A good example is Foster and Partners design for Terminal 3 of Beijing International Airport. This strategy is no different than Gaudi's stereostatic models of string and weights, or Candela's experiments with hy-pars. The second strategy is Simple Mathematical Geometry as used by Nervi in the Torino Espositioni or Foster + Partners in the Swiss RE Building. The third Strategy is Free Form, "development of the form independent [of] either physical constraints or the limitations of the simple mathematical geometries"[16] as Saarinen used to create the TWA Terminal and NOX used to create the H_2O expo. The last strategy Mangelsdorf mentions is a hybrid approach to design, to which he warns, "The compromises of this approach need to be tested against the initial concepts, requiring a high degree of coordination and trust between the architect and the engineer."[16] This is essentially the process Utzon and Arup utilized to simplify the shells of the Sydney Opera House. Essentially, the strategies for designing complex form are the same for analog or digital methods. Creative design abilities today are clearly linked to the limits of available software. Designers must understand more than the full breadth of software options. Digital design is a thought process; not an arbitrary movement of the mouse. Michael Meredith states, "Constructing narratives of utility provides an escape from a tautological parametric solipsism without forsaking formalism by providing an instrumentality of form, which could include pragmatic performance, the visceral, as well as the intellectual, discursive, or meaningful."[18] This may hold true for the creation of form for form's sake; but narratives define the rules, the processes, and the parameters encountered with real problems. Once defined in software, parameters direct the creative flow toward a solution. Even Meredith admits, "If anything an inclusive parametric process changes how we work, as well as our relationship to the 'office' itself. Parametric modeling is a discourse built upon techniques of either subdivision or aggregation".[18]

Virtual reality created a condition of acceptance of the lack of a perspectival hinge or for that matter, the lack of any plane of reference in the virtual world. Translated in architecture as a type of deconstructivism 2.0, the displacement of distortion of architectural elements is assisted by digital modeling as achieved by Frank Gehry with the Guggenheim Museum in Bilbao, Spain[26].

> "Gehry was skeptical at first, but once he recognized the ability of CATIA to translate his graphic and cardboard collage design gestures and its capacity to document complicated shapes in a way that did not baffle or intimidate contractors, he became a convert."[27]

Completed in 1997, the free-form structure was a melding of architecture, engineering and construction ingenuity.[28] Digital architecture is process driven, deriving from a methodology such as Meredith's narrative process: employing repetition and tessellations of basic structural knowledge as illustrated by Farshid Moussavi.[29] Moussavi sees basic historical structural geometries reordered into a differentiated, repeated state; a feat easily and more rapidly achieved with digital software. Regardless of the methodology of form-seeking in a digital world, the outcome is one of intensifying the user experience whether for sensory stimulation or environmental comfort by employing sets of rules to direct creative space-making. Termed the New Structuralism, the process necessitates a rethinking of the extents of design and the teaching of design.

Lars Spuybroek prefaces *The Architecture of Variation* with an assessment of the digital revolution. Spuybroek emphasizes the need for research in design and the need to research design itself. "Today, things have changed. Tools aren't fixed anymore… drawings have become files, architectural language has exploded, and criticality has become defunct – nothing is what it was, and everything seems to be fluid and vague. Design requires more and more research, since the transfer of data into architecture is without prefixed codes, without fixed forms or procedures. It is no longer enough that we do research before entering the design phase; we now have to research design itself. Obviously, as we enter a period in architecture in which things become less clear, our methods – both of teaching and design – must become increasingly precise and rigorous." [31] While Spuybroek sees a need to research the design process, Arup envisions the design process as collaboration on all levels. Jay Merrick, while speaking of Arup's Unified Design vision, states that "Essential architectural reference points

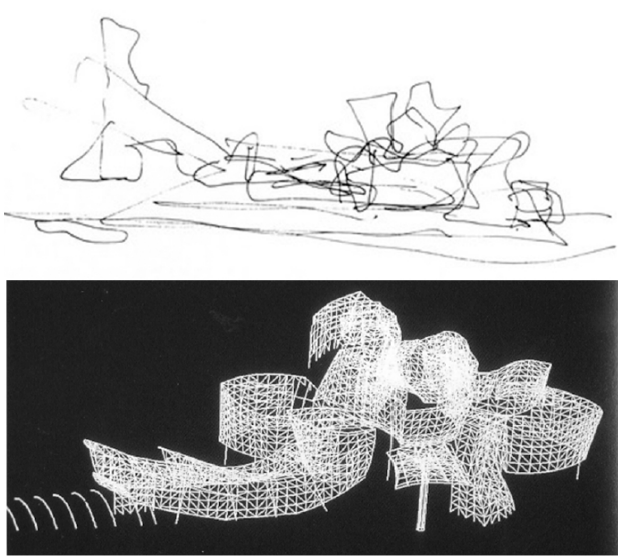

Figure 5. Sketch: Guggenheim Museum, Bilbao Source: Sony Pictures Entertainment Inc. Digital Model: Guggenheim Museum, Bilbao Source: James Steele, Architecture and Computers, New York: Watson-Guptill 2001

that once seemed usefully distinct – history, cultural norms, received notions of context and materiality – are today enmeshed and pixilated in the increasingly influential gravities of the virtual."[32] But further, the essay and the book, *Unified Design* envisions architecture as a collaborative process between engineer, architect and client with a social and economic responsibility.

The virtual creation of complex forms often requires physical large scale modeling for exploration into the design and tolerances of details and connections reminiscent of Saarinen's large-scale modeling. Research in parametric design is commonplace involving the conceptual parametrics of the virtual and the materiality of the physical – the prototype. It is the renewed and new interest in form, process and materials integration that drives design and the technology to support design. Fabrication at the forefront of design thinking is an integral element in returning the architect to the central position of Master Builder. Creative autonomy today wholly depends on acquired knowledge. "While the human mind may be bounded to the limitations of quantitative complexity, its computational extension, the computer, allows those boundaries to be surpassed."[33] Architecture today has the possibility of translating the virtual into the real, driving engineering and technology to keep apace of the complexities of material, fabrication and structure developed in the process. It is not a loss of perspective or respect for the vernacular; design thinking today is a process of responding to an evolution in thinking beyond reality to meet the ultimate needs of the user whether physical, emotional or spiritual. Armed with digital tools, creative autonomy is not only existent in the new structuralism, it is proliferative.

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