Yasha J. Grobman

Soft[ware] Boundaries: Complex Geometry in Architectural Design

Complex Geometry in Architectural Design – Exterior and Interior

Contemporary architects should consider themselves lucky to be able to create in this era. Until recently, both drawing and building construction were highly difficult in terms of geometry. As "architects draw what they can build and build what they can draw,"[1] the ability to design and build complex geometry[2] based buildings was a luxury limited to a small number of architects and projects in which time and money were of less concern. It is only in the last decade that assimilation and implementation of the use of new software and hardware computer tools and methods have made possible a proliferation of complex formal expression in modern architectural design. What began as technology-oriented evolution of design and building methods has brought architects to the position where they can draw and build almost without formal limits.

Computer power has been used to design and construct complex form for numerous buildings built during the last two decades. Early examples of such buildings are the Bercy project by Renzo Piano Building Workshop (1993), the Fish project in Barcelona (1993) and the Guggenheim Museum in Bilbao (1997) by Gehry Partners, and the utility building for the Water Pavilion in the Netherlands by NOX (1997).

The "new" formalism introduced by these buildings has been contentious right from the start. The configuration of the polemic has focused on the building's exterior, mainly through formalist perspectives of perception and performance.[3] The interior spaces, and more fundamentally, the new experiments in complex geometry in the interior (such as oblique or folded spaces) have been given much less attention in contemporary discourse. This might be explained by architects' emphasis on physical description as opposed to the situation oriented description (of events and effects) that is more appropriate to interior spaces[4]

Architectural theory regarding complex geometry emphasized the continuity of the space that is achieved by the unification of the wall, floor and ceiling into a singular continuous surface. The collapse of the differences between the various elements in the building was argued to blur the boundaries between internal spaces and between internal spaces and the exterior. The new formal world was seen as a shift to a more "natural" way of living or occupying space since it was a step towards closing the gap between landscape and architectural design in terms of morphological complexity.

Architects have now had almost 20 years of experience in the design, construction, and "consumption" of computer-aided complex-geometry buildings, and it is now possible to trace the various aspects of the influence of complex forms on the architectural profession and on the way we perceive and understand architectural space. Particularly, it is possible to examine the relationship between interior and exterior manifestations of complex geometry in buildings.

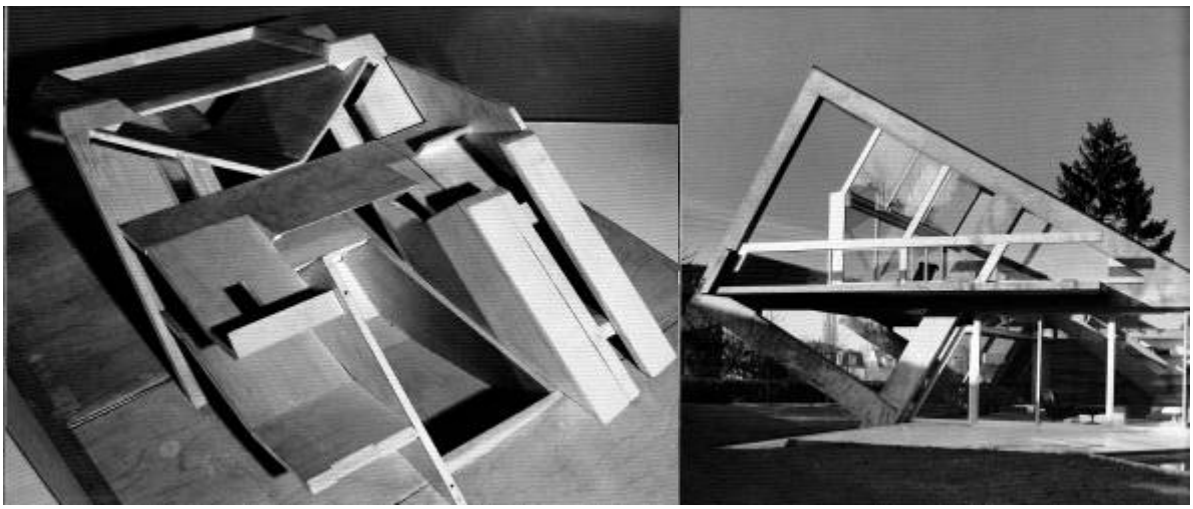
This paper essays an examination of possible shifts away from the supremacy of the orthogonal-horizontal in the surfaces of floors, and the definition of possible new types of non orthogonal space occupation by humans. It opens with a presentation and discussion of two different modern theories that have challenged the orthogonal nature of the floor surfaces in architecture. It goes on to characterize and discuss built examples of oblique or folded interior surfaces that were designed and built within the last 15 years, and concludes by developing a critical argument regarding current and future possibilities in non-orthogonal complex interior floor surfaces in architectural design.

The Folded, the Fluid, and the Oblique

"In effect, the static vertical and horizontal no longer correspond to the dynamics of human life. In future, architecture must be built on the oblique, so as to accord with the new plane of human consciousness. Any architectural programme that fails to do so will rapidly become useless."[5] Already in the late 1950s Paul Virilio had argued that the increasingly dynamic nature of modern life calls for a change in the way architectural spaces are articulated. According to Virilio, after the horizontal order of the rural habitat in the agricultural era, and the vertical order of the human habitat in the industrial era, the next logical step is the OBLIQUE

order of the post industrial age. To achieve this, it is necessary to discard the notion of the vertical enclosure, whose walls are made inaccessible by gravity, and to define habitable space by means of wholly accessible inclined planes, thereby increasing the usable surface area. Thus, "in contrast to partitions or vertical walls, which provoke an opposition between in front and behind a combination of oblique and horizontal plans would result only in above and below...".[6] As opposed to metaphoric approaches to motion, which were promoted in the 1950s and 1960s by architects such as Eero Saarinen[7], Virilio's approach to motion is non-metaphorical and thus suggests a sensual, not visual, feeling of motion.

The early Oblique Function Theory was developed within the frames of Architecture Principe, a multi-disciplinary group whose members were the philosopher Paul Virilio, the architect Claude Parent, the painter Michel Carrade, and the sculptor Morice Lipsi. The theory (named at that time "the function of the oblique") was examined in several conceptual and real architectural projects designed by Virilio and Parent during the 1960s. An examination of these projects reveals a deep disparity between the ideas and the realization. Looking at the suggested inclined surfaces it is quite clearly noticeable that the oblique surfaces are limited to spaces of movements (ramps) and to spaces where an inclination is defined by the programmatic needs as in the floor surfaces of halls. A real usable inclined surface that presents a novel typology for a new kind of program generated following Virilio's claim for a new "dynamics of human life", is not implemented in these projects (Fig. 1).



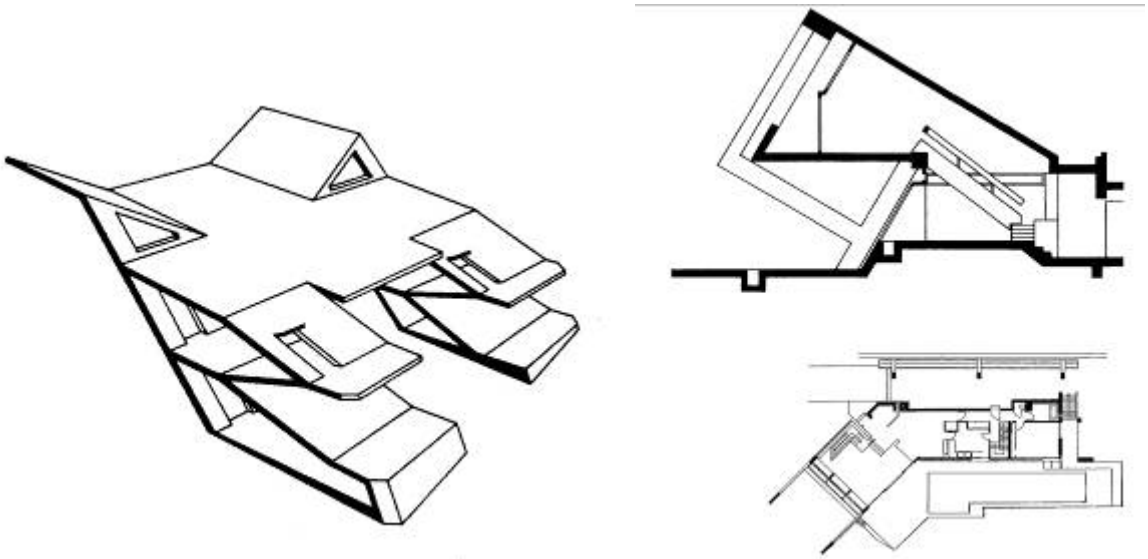


Fig. 1. Left: Claude Parent and Paul Virilio, Mariotti house (unrealized): above: photograph of model (1966); below: interior perspective (1966). Right: Claude Perent , Drusch house (realized): above: photograph (1962-3); below: ground floor and section.

Virilio himself confirms this observation in a later text from the 1970s. He claims that as a co-director of the Ecole Spéciale d'Architecture, he tried to develop technical research into the "organization and the precise morphology of oblique volumes", but after few years of "overwhelming difficulties of building an oblique habitat" decided to abandon this work.[8] Today, however, since some of the difficulties (mainly those related to technological issues) mentioned by Virilio have probably been overcome, and as the information technology (IT) revolution is making our lives increasingly dynamic, we perhaps need to reexamine the oblique theory. A partial answer to this question will be presented later in this text.

In the late 1980s, with the beginnings of the assimilation of the use of computers for design, architects started experimenting with complex geometry in design and manufacturing on grounds other than need. To a certain extent this marks the beginning of the second revolution in architecture (after the industrial revolution in the 19th century). Although both revolutions were led by technology, this revolution was electronic rather than mechanical.

One of the leading theories on complex geometry in architecture was developed by Greg Lynn during the early 1990s. In his seminal texts "The Folded, the Pliant and the Supple" and "Differential Gravities". Lynn argues for a need for a shift from the idea that buildings must stand up (in the literal sense) to gravity.[9] He offers a folded, curvilinear formal architectural

future in which “connections by vicissitude develop identity through the exploitation of local adjacencies and their affiliations with external forces”. Lynn suggests that a logic of a folded curvilinear formal world would result from the incorporation of external influences, but does not really define either the exact nature of these forces or the exact way in which they influence the architectural form. Lynn’s theory treats external and interior space in a similar fashion. In fact he claims that the fold unites exteriority and interiority into a single viscous space. Like Virilio, he calls for dynamic, non-orthogonal internal spaces. Lynn uses a burrow as an example of this type of space and as a contrast to the orthogonal static shelter. He sees the burrow as a “field of potential spaces”, but does not discuss the quality or the usability of this type of space. His example of a burrow, which is borrowed from Arnheim,[10] shows a section through a mole’s hill that contains only space for movement.

The Horizontal and the Vertical – Complex Geometry Beyond the Envelope In Built Contemporary Buildings

Although the number of buildings incorporating complex geometry has been increasing significantly in the last decade,[11] it seems that the number of buildings with complex geometry interiors is much smaller. The exact nature of interior spaces in contemporary complex geometry buildings is not easy to pin down. A close study of interiors based on curved or oblique surfaces in buildings built during the last two decades reveals that although there are numerous examples of complex geometry in the wall and ceiling surfaces, the floor surface is largely untouched and remains horizontal.

Technology is no longer a real limitation for curvilinear buildings. With the advance of parametric design and Building Information Modeling (BIM), architectural “objects are no longer designed but calculated,”[12] and buildings have begun being manufactured instead of constructed. Nonetheless, in this domain there are still many more examples of unbuilt work, especially when it comes to complex interior spaces. Some of the more famous built examples are: the Jussieu library by OMA (1993), which was developed as an inclined floor; Preston Scott Cohen’s Torus house (1998-1999), which morphs the vertical circulation surfaces with the horizontal floor surfaces; the Dom-In(fo) House project by Dagmar Richter, which shows how

with topological manipulation a modernistic project such as Le Corbusier's Maison Domino skeleton can be transformed into a continuous surface project (2002-2003); the winning entry for the Eyebeam Museum of Art and Technology in New York by Diller + Scofidio (2004), in which the building program is articulated between two folded surfaces; and the recent Sheikh Zayed National Museum in Abu Dhabi (2007) by Eisenman Architects, in which a complex 3-D pattern inspired by Muslim ornament is used as a base for the interior (Fig. **Error! Reference source not found.**2).

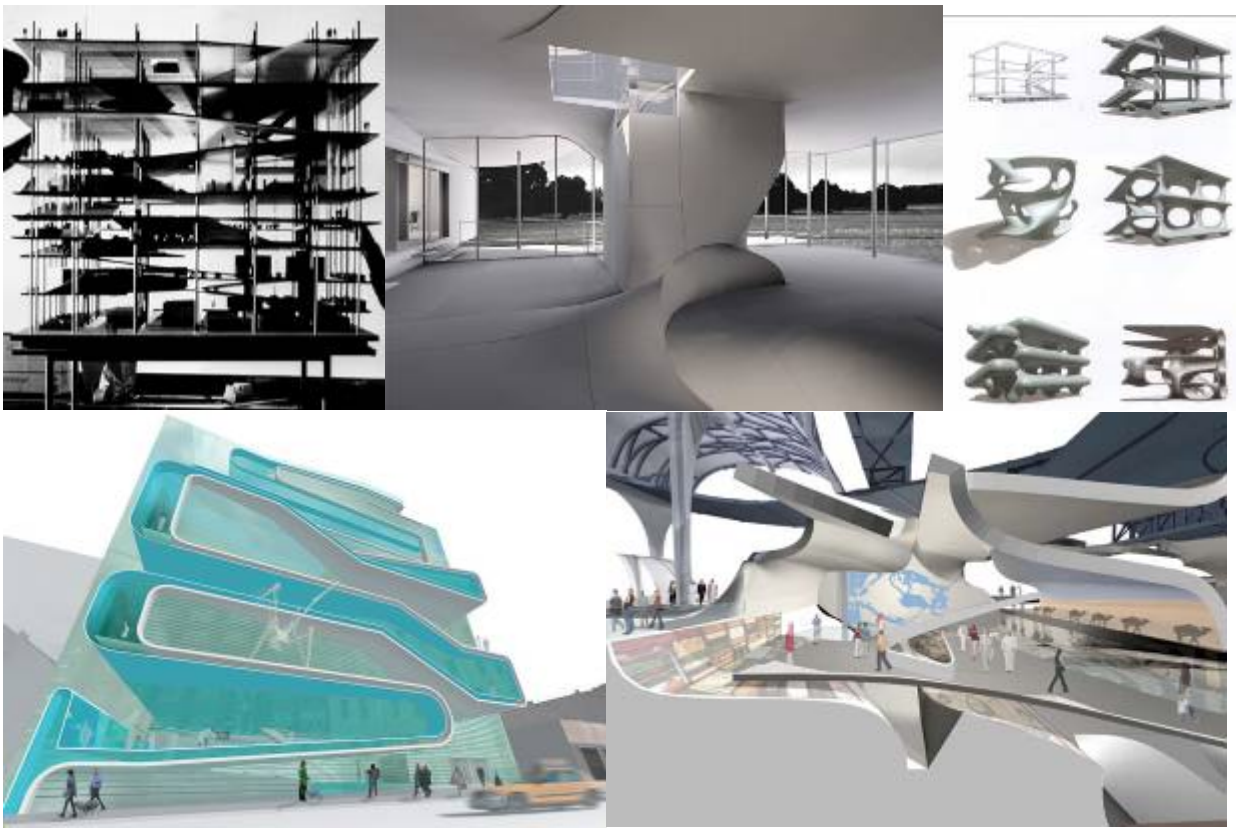


Fig. 2. Above, left to right: the Jussieu library by OMA (1993); the Torus house by Preston Scott Cohen (1998-1999; Dom-In(fo) by Dagmar Richter (2002-2003); below: the Eyebeam Museum of Art and Technology by Diller + Scofidio (2004); the Sheikh Zayed National Museum by Eisenman Architects (2007).

Since the early 1990s, however, folded and oblique floor surfaces can also be found in built projects. Examining these projects one can distinguish between two main approaches towards the articulation of the curvilinear or oblique floor surfaces. In the first approach the inclined or curvilinear floor surfaces seems to be used to achieve a perceptual effect. This is clearly related

to the more traditional image-based approaches to performance in architectural design that concentrate on the architectural object rather the human subject. In the second and more interesting approach the form is articulated in relation to the human subject. This approach emphasizes the tactile nature of surfaces and thus is oriented both toward the human body (senses) and the human eye (perception). It also suggests breaking dichotomies between the performance of form as an object and the performance of the human subject. The forms in this case are more animated, acting and interacting with the surrounding human subject, creating possibilities for the emergence of new realities.[13]

The first approach includes mainly projects with folded floors, in which the floor, wall and ceiling surfaces are merged into a single continuous surface. An early example of this type is the Educatorium campus center at the University of Utrecht by OMA (1997), and a later one is the Contemporary Arts Center in Cincinnati by Zaha Hadid (2003) (Fig. 3). It is clear that this approach pays less attention to functional aspects. In fact, it seems that it holds almost no direct functional possibilities as opposed to the strong visual/perceptual effects one experiences in this type of space.

Fig. 1 – Left: the Educatorium campus center at the University of Utrecht by OMA (completed in 1997); right: the Contemporary Arts Center in Cincinnati by Zaha Hadid (completed in 2003)

The very idea that the experience of space is ultimately dependent on the actions of the human body was mentioned already in the writings of thinkers such as Goethe and Merleau-Ponty. According to Goethe this factor has received less attention – perhaps because it is sometimes a more direct experience than vision, and does not require interpretation as does vision. The second approach to complex form for interior spaces investigates this domain. The

dynamic tactile nature of oblique or curvilinear floor surfaces is clearly related both to human perception and the physical sensation of instability while walking or standing on these types of surfaces. This notion of motion in architecture is more advanced then the metaphorical or metonymical ways of generating motion in building by imitating automotive or airplane design.[14] It is also arguably a less complex and more viable notion than kinetic architecture.

Already before the computer-based formal revolution in architectural design, oblique or curvilinear typologies for floor surfaces could be found in numerous architectural building types such as performance halls, parking lots and ramps.[15]

The new ideas of curvilinear (fluid) or oblique spaces can, therefore, be perceived as an attempt to extend the use of this type of morphology to other architectural functions that supposedly "correspond to the dynamics of human life" as called for by Virilio.

The question of what such "correspondence" might mean, however, has both general and specific aspects. The general aspect is whether the change in human life does in fact necessitate a typological change at all, while the specific aspect is whether the already built examples of curvilinear or oblique interior spaces hold a real possibility for a new and more dynamic way of living. The general aspect is hard to narrow down. Although the very idea of the IT revolution is about the motion or speed of information, it is still not clear whether rapid information distribution entails a spatial dimension. A similar line of argument to the one presented earlier on motion in architecture could be applied in this case too. According to this argument the speed of information and the fact that human life has become more dynamic does not necessarily have to be replicated in the physical world. Indeed, quite the opposite may be the case: it can be argued that since humans have the ability to virtually communicate at unprecedented speeds, their need for physical motion actually decreases. This argument is also supported by late American statistics that show the general level of physical activity is declining.

The specific aspect of the question is somewhat simpler. If we exclude pavilions, exhibitions and other spaces that are either temporary or experimental such as NOX's Water Pavilion, the remaining number of built buildings in which curvilinear or oblique floors are to be found is rather small. Moreover, within the group of contemporary buildings with inclined or curvilinear floors one can hardly find even a single example in which the floor's surface serves for a new type of program that is influenced by the IT revolution. In the vast majority of these

buildings, such as the VPRO Broadcasting Company by MVRDV (completed in 1997; Fig. 4) or the Yokohama International Port Terminal by Foreign Office Architecture (FOA) (competition in 1995, completed in 2002; Fig. 5), the oblique floor spaces are still intended to be used for circulation or for symbolic and perceptual effects rather than suggesting a new formal approach for space occupation.

Fig. 4. VPRO Broadcasting Company by MVRDV

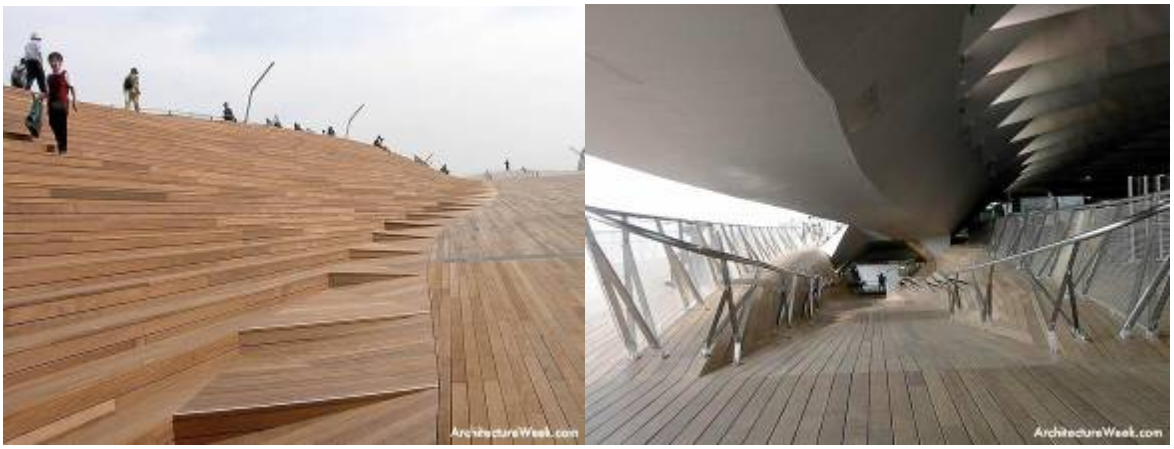


Fig. 5. Yokohama International Port Terminal by Foreign Office Architecture

Landscape Interiors

Unlike designers of buildings, landscape designers have continuously been using curvilinear geometry in ground surfaces of landscape architecture. This may well be the reason why one can hardly find a contemporary discourse questioning the influence of technology on landscape architecture in relation to complex geometry and more specifically to curvilinear and oblique

surfaces. There are, naturally, major differences between architecture and landscape design in relation to the question of complex geometry, in terms of both function and usability. The main differences are: the multilevel perception of architectural design as opposed to the mainly single surface perception of landscape; the notion of shelter and resting-place that is connected to horizontality and stability as opposed to motion, which is suggested by inclined surfaces; and the complexity of the integration of furniture and building appliances into floor surfaces of complex geometry interiors. A curvilinear or oblique interior will necessitate a change in the way furniture and appliances are manufactured or connected to the floor surface. This could be done by developing the furniture as a second continuous surface layer similar to the way suggested by Kolatan McDonald (Kol/Mac) in the Ost-Kuttner Apartment project[16] (Fig. 6).

Fig.6. Ost-Kuttner apartment by Kolatan MacDonald Studio (1997)

This would make the spaces highly customized and tailored to the customer, but not as flexible as an anonymous orthogonal space. Alternatively, when using a detached furniture approach, curved and oblique floor surfaces would necessitate an exact and different interface for furniture at every single point. Both approaches may well become the source of a paradigm shift in interior design, in which standard-oriented design and manufacturing will be superseded by computer-controlled “one of a kind” manufacturing or at least a highly customized version of mass-customization.

Complex Interiors and Sustainability

Architecture is clearly moving towards a more sustainable future, one that might suggest a shift in the relationship between nature and architecture, in terms of both material and geometry. Such a shift would include a different, more quantitative approach towards material and form as opposed to the mainly perceptual approach that is related to changes of intensity of human life. A quantitative approach would rely on computer simulation and optimization of various environmental criteria that would allow better efficiency in the use of both material and energy resources. Examples of this type of approach are the computer-based non-linear form generation methods, which are based on performance criteria such as loads, winds, and acoustics. These methods generate performance-oriented architectural forms that are naturally non-orthogonal.[17]

Epilogue

While complex geometry seems to be already assimilated into contemporary architectural practice that relates to building envelopes and interior partitions, interior floor surfaces have not been profoundly examined. Although some of the arguments for the need of curvilinear or inclined surfaces in interior floor surfaces are still questionable – as with the notion of dynamic space in the "Function of the Oblique" theory, it may well be that it is too early to arrive at a general conclusion on this matter. Perhaps only the next stages in the technological revolution in architecture will be able to provide an answer. These stages would need to include a comprehensive solution to other elements that form part of the interior space, such as furniture and appliances, and a more performance-oriented quantitative approach to environmental criteria in buildings. These changes would potentially demonstrate whether the curvilinear and inclined surface holds a genuine performance-oriented prospect for architectural design, or will remain merely one more "tool" among many in the image-based or perception-oriented formal repertoire of architecture.

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[1] William J. Mitchell, "Roll Over Euclid: How Frank Gehry Designs and Builds," in *Frank Gehry, Architect*, ed. Frank O. Gehry and others (New York: Guggenheim Museum Publications, 2001), pp. 352-363.
[2] Complex geometry in this context refers to both curvilinear and tessellated inclined surfaces which cannot be easily expressed in traditional plan based drafting conventions nor built using standard elements.
[3] Sanford Kwinter, "Who's Afraid of Formalism?," in *Phylogenesis: Foa's Ark*, ed. Foreign Office Architects (Barcelona: Actar, 2004).
[4] Mohsen Mostafavi, "Architecture's Iinside," *Harvard Design Magazine*, no. 29 (Fall/Winter 2008).
[5] Claude Parent and Paul Virilio, *The Function of the Oblique: The Architecture of Claude Parent and Paul Virilio 1963-1969*, ed. Pamela Johnsoton (AA Publications, 2004), p. 65.
[6] *Ibid.*, p 13.
[7] For example, in his design for the TWA terminal, with its roof shaped like extended wings, at JFK airport in New York, 1956-62.
[8] Parent and Virilio, *The Function of the Oblique*, p. 13.
[9] In Greg Lynn (ed.), *Folding in Architecturei*. First published in *Architectural Design* 63, nos.3-4 (1993), entire issue; and since in revised editions:(Brussels: La Lettre Volée, 1998; Hoboken, NJ: Wiley-Academy, 2004).
[10] Rudolf Arnheim, *The Dynamics of Architectural Form: Based on the 1975 Mary Duke Biddle Lectures at the Cooper Union* (Berkeley: University of California Press, 1977).
[11] Jacob Yasha Grobman, *Building the Digital World – Architectural Design Methods Based on the Use of Digital Tools – Performance Based Form Generation and Optimization* (Ph.D. diss., Haifa: Technion, Israel Institute of Technology, 2008).
[12] Bernard Cache, *Earth Moves: The Furnishing of Territories* (Cambridge, Mass.: MIT Press, 1995).
[13] Eran Neuman and Jacob Yasha Grobman, "Performalism: A Manifesto For Architectural Performance," in *Performalism: Form and Performance in Digital Architecture* (Tel Aviv: Tel Aviv Museum of Art, 2008).
[14] For an introduction to the various ideas of motion in architecture, see Kari Jormakka, *Flying Dutchmen: Motion in Architecture*, (Basel: Birkhäuser [IT Revolution in Architecture series], 2002).
[15] In fact, some well-known modern 20th-century buildings include oblique or curved floor surfaces, among them the New York Guggenheim Museum by Frank Lloyd Wright, which is designed as a continuous oblique exhibition space, and Oscar Niemeyer's Communist Party Building in Paris, which has a curvilinear inclined floor in the lobby space of the auditorium.
[16] Peter C. Schmal and Ingeborg Flagge, *Digital Real: Blobmeister: First Built Projects*, 1st ed. (Basel: Birkhäuser, 2001).
[17] Jacob Yasha Grobman, Abraham Yezioro and Isaac Guedi Capeluto, "Building Form Generation Based On Multiple Performance Envelopes", in *25th Passive and Low Energy Architecture Conference* (Dublin, 2008).