SYMBOLS OF EVOLUTION, SIGNS OF REGRESSION: MIES AND THE POLITICS OF GEOMETRY

MICHAEL OSTWALD
School of Architecture and Built Environment
The University of Newcastle

The architecture of Mies van der Rohe, from its early crystalline forms to its later more orthogonal compositions, has been the site of a range of conflicting interpretations. At the center of several of these debates has been the question of whether Mies's use of geometry represents an enlightened or progressive approach to society, or whether it is simply a sign of cultural regression and the failure of Rationalist thought. Curiously, in many of these debates, Mies's architecture has become secondary to the way in which geometry can be deployed for political purposes. This paper looks at one such proposition about Mies and geometry, from the mathematician Benoit Mandelbrot, and the political purpose of this argument which is the suggestion that Euclidean geometry is unnatural and regressive.

The focus of this paper is mathematical interpretations of architecture and geometry. Specifically, this paper examines the structure and basis for Mandelbrot's argument drawing conclusions about the way in which geometry may be deployed for political purposes and is also particularly open to such operations. In this way the paper supports Robin Evan's assertions about appropriated geometry and the naïve assumption that it is theoretically inert.

INTRODUCTION

In *The Projective Cast* Robin Evans argues that the presence of a system of geometry underlying the production of architecture is assumed in much the same way that the "presence of mathematics is assumed in physics, or letters in words."[1] In this sense, geometry plays a foundational or formative role as it both supports and frames architecture. Despite this, because geometry is traditionally the province of the mathematician or scientist, architecture does not produce systems of geometry, it appropriates and consumes them. As Evans records,

> [g]eometry is understood to be a constitutive part of architecture, indispensable to it, but not dependent on it in any way. The elements of geometry are thus conceived as comparable to the bricks that make a house, which are reliably manufactured elsewhere and delivered to site ready for use. Architects do not produce geometry, they consume it. Such at least would be the inevitable conclusion of anyone reviewing the history of architectural theory.[2]

However, for Evans geometry is no so digestible as architects imagine. Geometry is never truly subsumed in architecture and because it retains a degree of autonomy, it necessarily provides a possible connection to mathematics, science and, through semiotic and epistemological operations, to other disciplines. This possible connection exists, and remains after the architectural design process is complete because, to use Evans's words, the geometry has been "manufactured elsewhere" and resists complete transformation into architecture. Evans proposes that architects have such a "seemingly unlimited faith in the power of geometry"[3] that the first incursion into another discipline is frequently associated with an attempt to procure and then consume geometry. That the geometry remains largely undigested in the architectural design process is also a factor of its acknowledged origins in another discipline. Moreover, architects rarely procure geometry in a clandestine manner; the presence of a system of geometry in architecture is typically celebrated in an attempt to provide an incontrovertible source of authority for design rhetoric and production.[4]

These characteristics of geometry in architecture-its foundational role, its overt status, its exteriority and the associated authority derived from these-leave architecture vulnerable to being interpreted simply as an extension of geometry. While to an architect this may seem a peculiar proposition, to a mathematician or scientist such a reading of architecture is perfectly natural. Moreover, just as architects appropriate geometry for the purpose of supporting their arguments, so too mathematicians appropriate architecture for similar reasons.[5]

The present paper is concerned with the way in which several mathematicians, and specifically Benoit Mandelbrot, have used Modern architecture and the works of Mies van der Rohe (and the Euclidean geometry they suppose such works embody) for political and personal purposes. Thus the focus of this paper is a close reading of mathematical claims about architecture that have been made by way of geometry. This paper is not concerned with whether the mathematicians' claims about architecture are valid or correct (which they typically are not[6]) but rather how architecture is used for political purposes and whether such an analysis supports Evan's thesis about the ability of geometry to resist singular and stable interpretations.

MODERN ARCHITECTURE - EUCLID'S LEGACY

In 1977 the scientist Benoit Mandelbrot's seminal work *Fractals: Form, Chance, and Dimension*, the first English language edition of his 1975 *Les Objects Fractals: Forme, Hasard et Dimension*, was published to much critical acclaim. Although Mandelbrot had published many papers prior to this date, the formal science of chaos theory is widely considered to be defined by this work. However, like the mythopoeic "death of modernism" manifest in the demolition of Yamasaki's *Pruitt-Igoe Housing* in 1972, this birthdate for chaos theory is contentious. What is certain is that within *Fractals: Form, Chance, and Dimension*, Mandelbrot not only combines his observations of the geometry of nature for the first time but he also makes the first of a number of well documented forays into art and architectural history and critique. While this is not the first instance of a scientist or mathematician working within the sciences of complexity venturing into architectural territory, it is nevertheless the first clearly recognised example of such an event.

Mandelbrot's professed enthusiasm for architecture, painting and music leads him to use metaphors from each of these disciplines to explain his mathematical theories. Mandelbrot however, rarely appropriates solely for instructional purposes. For example, when trying to explain the significance of fractal geometry to non-scientific disciplines he indulges in both a critique of architectural movements as well as in an act of censure directed at a fellow complexitist. In both cases the resultant attempt to draw authority through analogy all but obliterates any possible pedagogical intent.[7] This example from Mandelbrot starts as follows.

> A paradox emerges here: As observed in Dyson's quote [...] modern mathematics, music, painting, and architecture may seem to be related to one another. But this is a superficial impression, notably in the context of architecture: *A Mies van der Rohe building is a scalebound throwback to Euclid, while a high period Beaux Arts building is rich in fractal aspects.*[8]

At its most obvious level, here Mandelbrot is disagreeing with the mathematician Freeman Dyson on the grounds that modern architecture is not fractal; not that Dyson ever made such a suggestion.[9] Contrary to Mandelbrot's claims Dyson's 1978 paper *Characterizing Irregularity* not only never mentions architecture but only makes passing reference to music and the arts. Even more intriguingly, Dyson's paper which Mandelbrot is using as a licence to appropriate from architecture, is simply a review of an earlier edition of Mandelbrot's own book! Thus a quixotically self-referential motive for writing about architecture is uncovered. To reiterate; Mandelbrot quotes at length a review of his own work in the revised edition of the same book without reference to the intent of the review. Moreover he then uses this review as a catalyst for discussion of a concept that, despite appearances, he has manufactured entirely. Ignoring for the moment that the fomenter for Mandelbrot's appropriation is not as he has claimed, what then is Mandelbrot's motivation for marauding so willfully into architecture? This is the question that the remainder of this paper answers.

Like fellow mathematician Gert Eilenberger, Mandelbrot uses architecture to metaphorically differentiate between fractal and Euclidean systems of geometry.[10] In order to draw this distinction he resorts to an argument with aesthetic overtones because he believes that fractals *are* the geometry of nature and nature is considered, by the complexitists at least, to possess an almost teleological beauty. While Eilenberger constructs his argument around a confusing and arbitrary distinction between the Gothic and the Baroque, Mandelbrot constructs a similarly unsupported case concerning Beaux-Arts and Modernist architecture. Yet, as is the case with Eilenberger, Mandelbrot's claims are difficult to interpret primarily owing to his idiosyncratic understanding of architecture. Despite these difficulties the attempt to unravel the complex motives surrounding Mandelbrot's fractal architecture is worth pursuing.

One of the many problems with Mandelbrot's use of architecture is that his judgements are based upon a purely visual value system that is derived from a superficial study of the facades of buildings. For one thing, exactly what Beaux-Arts tradition is Mandelbrot discussing? Is he referring to the artistic and craft-based tradition of the Ecole des Beaux-Arts; a tradition often linked to the works of Semper? Is he referring to the end period of the Gothic revival in the nineteenth century - a period that segued into Art Nouveau? If it is to this *fin de siécle* style, then does Mandelbrot understand that it is characterised, in architecture, by an axial layout, strong bilateral symmetry and Euclidean geometric planning? Even if this is the case, a Beaux-Arts building, while deceptively organic in its decoration, possesses no more, and possibly less, true self-similarity (and surprisingly little statistical self-similarity) than say, a Gothic cathedral. Yet Mandelbrot raises the Beaux-Arts building, and the Paris Opera in particular, above the work of Modern architecture on aesthetic grounds because he considers the former closer to the geometry of nature.

It starts to become apparent, when cross-checking other papers published by Mandelbrot at that time, that the *fin de siécle* tradition in France, which preceded the rise in Art Nouveau, is indeed the Beaux-Arts style he is referring to. For example, in his 1981 paper, *Scalebound or Scaling Shapes*, Mandelbrot provides a more detailed explanation of fractal geometry in association with architecture.

> It is often said that 20th-century "modern" buildings are sterile, not built to human scale and, in fact, unnatural. The more I ponder such statements and their variants, the more elusive I find their meaning and the more I feel that a discussion of the logic and of the aesthetics of the notion of scale needs to be resumed. Clearly, a building's absolute or even relative height and number of stories are incidental and other aspects of scale are more important: I propose that it might be interesting to introduce into aesthetics the distinction between scalebound objects and scaling objects, a broad distinction that is proving increasingly useful in several scientific contexts. One of my conclusions is that it is fruitful to call Mies van der Rohe's buildings scalebound-a term a physicist would use to describe a flawless crystal and the solar system-and to call the Paris Opera House a scaling building-the term scaling also being applicable to typical views of the Alps and to the visual characteristics of many other objects in nature, some of them visible (large or small) and others invisible to the naked eye.[11]

Garnier's 1874 *Paris Opera House*, described in *Sir Bannister Fletcher's History of Architecture* as a development of Baroque aesthetics on a Beaux-Arts plan, is therefore, for Mandelbrot, the epitome of fractal architecture. Yet, despite the contestable nature of this claim it is elaborated and repeated with little critical comment in many works that follow in both Complexity Science and, somewhat ironically, in architecture.[12] For example, James Gleick follows Mandelbrot in describing "the architecture of the Beaux-Arts, with its sculptures and gargoyles, its quoins and jamb stones, its cartouches decorated with scrollwork, its cornices topped with cheneaux and lined with dentils"[13] as a perfect example of fractal architecture.

> A Beaux-Arts paragon like the Paris Opera has no scale because it has every scale. An observer seeing the building from any distance finds some detail that draws the eye. The composition changes as one approaches and new elements of the structure come into play.[14]

In like manner, John Briggs in *Fractals, the Patterns of Chaos* focuses on the *Paris Opera House* with its "fine layering of self-similar detail"[15]. "As one walks down Rue de l'Opera", he records, "the closer one gets, the more of the building's self-similar detail comes into view."[16] Yet for Briggs, the parallels Mandelbrot draws between fractal geometry and Beaux-Arts architecture are a "seemingly odd comparison"[17] because the *Paris Opera House* clearly has little in common with the forms of nature other than detail at a number of scales. So the question remains, why appropriate architecture in this particular way?

For Mandelbrot architecture is a useful device for insinuating his own covert arguments into the mind of the reader even while ostensibly offering an unbiased explanation of a scientific concept. For example, when making the claim that certain forms of art are accepted by the general populace, because they possess geometry similar to that present in nature, Mandelbrot returns to the Beaux-Arts tradition.

> The fractal "new geometric art" shows surprising kinship to Grand Masters paintings or Beaux-Arts architecture. An obvious reason is that classical visual arts, like fractals, involve very many scales of length and favor self-similarity. For all these reasons, and also because it came in through an effort to imitate Nature in order to guess its laws, it may well be that fractal art is readily accepted because it is not truly unfamiliar. Abstract paintings vary on this account: those I like also tend to be close to fractal geometric art, but many are closer to standard geometric art-too close for my own comfort and enjoyment.[18]

In this case Mandelbrot's reason for viewing Beaux-Arts architecture as superior to Modernist architecture is slightly more lucid although still unconvincing. In that certain artistic (and also architectural) traditions attempt to uncover the geometric basis for natural forms those forms of art, or architecture might exhibit, superficially, the characteristic complexity of fractal form. Nevertheless, Mandelbrot once again uses his explanation of beauty in art as a chance to criticise abstract painting; perhaps for the same reason he frequently condemns modern architecture. Still, in concentrating on Mandelbrot's erratic reading of historic architectural styles the reader is simply left with more questions. Perhaps a clue might be found on the other side of the equation - Modern architecture.

While Mandelbrot's Beaux-Arts tradition (as an example of fractal architecture) is somewhat poorly defined in his early works, his description of not-fractal architecture is anything but imprecise. Not only is modern architecture in general considered anti-fractal but the work of one architect in particular, Ludwig Mies van der Rohe, is singled out as exemplar of not-fractal. Moreover the Miesian skyscraper is described in such a way that it is emblematic of the general malaise afflicting modern cities and societies. As Kavannagh records in his 1992 paper, *Chaos in Architecture*, "Mandelbrot suggest[s] that modern buildings are too heavily influenced by traditional geometry" and for this reason they are deemed to be unnatural because they do "not relate to 'nature's geometry', to Fractal geometry."[19] Mandelbrot's colleague, Richard Voss, reiterates this position. "The crowds and dirt" he states, "may not be the only reasons why people often feel alienated in modern cities. The shape of buildings and grid-like regularity of the streets are intrinsically alien"[20]. Gleick similarly summarises Mandelbrot's intentions by noting that for

> Mandelbrot the epitome of the Euclidean sensibility outside mathematics was the architecture of the Bauhaus. It might just as well have been the style of painting best exemplified by the color squares of Josef Albers: spare, orderly, linear, reductionist, geometrical. Geometrical-the word means what it has meant for thousands of years. Buildings that are called geometrical are composed of simple shapes, straight lines and circles, describable with just a few numbers. The vogue for geometrical architecture and painting came and went. Architects no longer care to build blockish skyscrapers like the Seagram Building in New York, once much hailed and copied. To Mandelbrot and his followers the reason is clear. *Simple shapes are inhuman. They fail to resonate with the way nature organizes itself or with the way human perception sees the world.*[21]

Mandelbrot is not alone in offering such dubious and simplistic descriptions of architecture in opposition to nature. Mathematicians Peitgen and Richter quote extensively from Friedensreich Hundertwasser who even more forcefully and openly connects Euclidean geometry to architecture; their coalition causing, in Hundertwasser's view, the demise of society.

> In 1953 I realized that the straight line leads to the downfall of mankind. But the straight line has become an absolute tyranny. The straight line is something cowardly drawn with a rule, without thought or feeling; it is the line which does not exist in nature. And that line is the rotten foundation of our doomed civilisation. Even if there are places where it is recognized that this line is rapidly leading to perdition, its course continues to be plotted ... *Any design undertaken with the straight line will be still born.* Today we are witnessing the triumph of rationalist know how and yet, at the same time, we find ourselves confronted with emptiness. An esthetic void, desert of uniformity, criminal sterility loss of creative power. Even creativity is prefabricated. We have become impotent. We are no longer able to create. That is our real illiteracy.[22]

Modern architecture might represent for Mandelbrot order, precision and a means of explaining the fractal concept but it is appropriated for other purposes entirely. Modern architecture represents for Mandelbrot and his followers all that is wrong in the synthetic, mediated world. The *Paris Opera House*, as Briggs infers, is not a convincing example of fractalesque form. Given this situation it must be assumed that the purpose of setting up an oppositional system (fractal architecture versus non-fractal architecture) is not to valorise the Beaux-Arts tradition but instead to criticise Modern architecture. Architecture is appropriated for the purpose of creating a picture of the world that is stifled and choked by Modernist architectural excesses. In proffering this image, the humble fractal is able to be portrayed as an anodyne; a cure for societal ills.

Mandelbrot's argument constructs a binary opposite that gives power precedence, or legitimacy to the fractal (and the mathematician who developed the concept) and denigrates Euclidean or orthogonal geometry. Further evidence towards this position is found in Noel Gray's reading of Mandelbrot's motives for writing first *Fractals: Form, Chance, and Dimension* and later revising it as *The Fractal Geometry of Nature*. Gray's critique of Mandelbrot's motives for promoting fractal geometry is particularly telling. For Gray, Mandelbrot's basic argument is that "[f]ractal geometry deals with the real world of everyday perception [...] Fractal geometry is nature's own geometry" and "[f]ractal geometry imitates nature's process of change."[23] As the art critic Peter Fuller presciently records,

> [it] is Mandelbrot's audacious claim that he has conceived an entirely new geometry of nature which is capable of describing, and indeed of replicating, many of the irregular and fragmented patterns which abound in, say, leaves, coastlines, trees and mountain ranges.[24]

By reinforcing the relationship between fractal geometry and the geometry of nature the reader of Mandelbrot is left with the impression that fractal geometry *is* the geometry of nature; this is not so. Fractal geometry is simply a better system of replicating or modelling natural forms than Euclidean geometry is. In Mandelbrot's "argument, fractal geometry is thus not simply another system of static measurement; rather, it duplicates to all intents and purposes the actual process of the generation of nature's complexity."[25] For Mandelbrot, Gray states, "[f]ractal geometry is the practice of this truth. It is worth emphasizing that this notion of an unproblematic transcendental truth, truth-to-nature, is the pivotal point of this practice."[26] Thus Mandelbrot's aesthetic must be "basically Kantian in character"[27] (in that he believes in a universal unquestionable form of beauty) if he is to support his greater claim that fractals are the geometry of nature. If, as Gray argues, Mandelbrot's aim is to equate fractal geometry with the geometry of nature (an argument tellingly mirrored in the change in naming of Mandelbrot's seminal text from *Fractals: Form, Chance, and Dimension* to *The Fractal Geometry of Nature*) then he has to somehow construct a system whereby fractal geometry is seen as positive (because it is natural) and conversely the geometry of Euclid is seen as negative. To fulfil these aims Mandelbrot needs something to play the metaphorical role of Euclid's legacy; Modern architecture simply and efficiently fulfils this role.

Mandelbrot is not alone is using Modern architecture as a scapegoat. John Barrow in a discussion of fractal geometry and aesthetics similarly proposes that all "aesthetic preferences are a fusion of instinct and experience", but that "in the absence of experience and special influence, our innate sensitivities"[28] recognise the true beauty of nature! Barrow dismisses a love of abstract art as a trained and thereby polluted appreciation of form. "Our artistic fascination", he states, is with natural forms, "with sunsets and cloud patterns"[29]; Barrow's aesthetic is thus, like Mandelbrot's essentially Kantian in character. Barrow uses two time-honoured approaches to make this argument. In the first instance he simply claims that to those untrained in aesthetics, landscape paintings are beautiful while abstract art (as exemplified in the works of Mondrian or Albers) is not. His second argument is that nature is good for humanity because it provides shelter, sanctuary and a sense of place. As evidence towards this valorisation of primitive huts and savages (more in the mould of Constable than Rousseau) he cites the denial of these characteristics in Modern architecture.

> Their denial in many urban building projects has had consequences that are all too plain to see. Concrete, exposed walkways, innumerable blind corners, greyness, and banal predictability, which offer no refuge from everyone else, and buildings that offer no enticement to enter: these abominations have led to depression, crime, and emotional disequilibrium.[30]

An accompanying illustration of an anonymous, Modernist office tower is described as an "unpleasant urban building that offers no sense of providing entry or refuge."[31] In contrast three paintings, Turner's *Petworth Park* (1828), Martin's *The Bard* (1817) and Lessing's *Castle on the Rocks* (1828) are presented as depicting the lyrical relationship between nature and man. Modern architecture once again is the disease and fractal form (inasmuch as it represents a return to nature) is the cure. The motive for appropriating architecture is simply to provide circumstantial evidence for the power of the fractal.

Finally, returning to Mandelbrot's appropriations from architecture, it cannot be denied that there is an emotive dimension to the argument that, while less obvious, nevertheless plays an important role. As simplistic as it sounds, many people in society, regardless of their disciplinary backgrounds, have strong nostalgic yearnings for historic works of architecture. In the twentieth century attacks on Modern architecture[32] and praise for the restoration and retention of historic buildings are common in the popular press.[33] By playing on this emotional reaction to historic buildings as good and modern

buildings as bad, Mandelbrot is effectively able to convincingly promote the fractal as anodyne. As simplistic as it sounds, Mandelbrot is able to gain personal and political authority through this analogy.[34]

CONCLUSION

Fundamentally Mandelbrot uses architecture, as embodiment of geometry, for political reasons not spatial formal or stylistic ones. Mandelbrot's central thesis is that fractal geometry is the geometry of nature and that it must therefore be beautiful (because nature is beautiful). Conversely he argues that Euclidean geometry is unnatural, and is therefore ugly. In order to make this simplistic case Mandelbrot needs to align his fractal geometry with some emotive examples drawn from art, architecture and design. From the latter categories he chooses the popular landmark, the *Eiffel Tower* and a famous and well-loved historic building, the *Paris Opera*. From the former he identifies the architecture of Mies which, through its presumed association with Nazi architecture and in part as a result of its geometric basis, is already laden with political intrigue.[35] For example, writing in 1968 Barbara Miller Lane laments that as a result of the rise of the Modern Movement the "'New Man' is no longer a man, he is a 'geometric animal'" who has no need for a conventional home but seeks instead an archetypal "machine for living in".[36] Because this New Man is not an individual, but a "piece of mass man" the architecture is presumed to have a regressive role in limiting the person's potential individuality.[37] Mies's often orthogonal architecture, much like Hilbersheimer's, has attracted criticism, much of it unfounded, because it represents a rigorous application of geometry that coincided with the rise of the Modern Movement and straddled the rise and fall of the Third Reich.[38] For this reason Mandelbrot's argument that orthogonal geometry is regressive while complex, iterative, organic geometry is progressive finds diffuse, if debatable, support in architectural writings.

One of the reasons that architecture is able to used in this way, as an extension of geometry, for political purposes is because it is assumed to be, metaphorically speaking, stable, inert, or dead. As Evans asserts,

> [f]rom the point of view of the architect seeking firmness and stability, the best geometry is surely a dead geometry [...] What I mean by a dead geometry is an aspect of geometry no longer under development from within. Triangles, rectangles, and circles as defined in Euclid have been pretty well exhausted as subjects of geometrical enquiry. As these elements lose their mystery, interest in them subsides, but in this state of devaluation they become more valuable elsewhere because their behavior is completely predictable. Consequences can be foreseen. Dead geometry is an innoculation against uncertainty.[39]

Dead geometry provides stability for the generation of architectural forms - it creates "certainty in situations beset by doubt."[40] However geometry is never really dead and fittingly, for Evans, the inevitable result of such a false assumption is that the appropriated body of geometry may become animate once more and may be employed for a range of purposes, including the political and personal arguments of mathematicians. Evan's reading of geometry's ability to animate and undermine the architecture it is supposed to be framing, is supported by the present analysis.

1 Robin Evans, *The Projective Cast: Architecture and its Three Geometries*, Cambridge, Massachusetts: MIT Press, 1995, p. xxvi.

2 Evans, *The Projective Cast*, p. xxvi.

3 Evans, *The Projective Cast*, p. xxv.

4 See: Paul-Alan Johnson. *The Theory of Architecture: Concepts, Themes and Practices*. New York: Van Nostrand Reinhold, 1994.

5 Michael J. Ostwald and R. John Moore, 'Unravelling the Weave: An Analysis of Architectural Metaphors in Nonlinear Dynamics.' *Interstices*, 4 (1997): CD-ROM

Michael J. Ostwald and R. John Moore, 'Mathematical Misreadings in Non Linearity: Architecture as Accessory/Theory.' In Mike Linzey, ed. *Accessory/Architecture. Volume 1*. Auckland: University of Auckland, 1995. pp. 69-80.

6 Michael J. Ostwald and R. John Moore, 'Fractalesque Architecture: An Analysis of the Grounds for Excluding Mies van der Rohe from the Oeuvre.' In A. Kelly, K. Bieda, J. F. Zhu, and W. Dewanto, eds. *Traditions and Modernity: Contemporary Architecture in Southeast Asia and Beyond*. Jakarta: Mercu Buana University, 1996. pp. 437-453.

7 For a detailed analysis of the strategy of promoting "authority through analogy" in architectural theory see: Michael J. Ostwald, 'Architectural Theory Formation Through Appropriation.' *Architectural Theory Review*, 4, 2 (1999): pp. 52-70.

8 Benoit B. Mandelbrot, *The Fractal Geometry of Nature*. New York: W. H. Freeman and Company, 1982. pp. 23-24. my italics.

9 Or at least not in the particular reference Mandelbrot cites. cf. Freeman Dyson. "Characterizing Irregularity." *Science*, 200 , 4342 (May 12, 1978): pp. 677-678.

10 Eilenberger, Gert. 'Freedom, Science, and Aesthetics.' In Heinz Otto Peitgen and Peter H. Richter eds. *The Beauty of Fractals*. New York: Springer-Verlag, 1986. pp. 175-180.

11 Benoit B. Mandelbrot, 'Scalebound or Scaling Shapes: A Useful Distinction in the Visual Arts and in the Natural Sciences.' *Leonardo*, 14 (1981): p. 45.

12 Both Kavannagh and Fuller have accepted Mandelbrot's assertions largely without question. cf. John A. Kavannagh, "Chaos in Architecture." *Irish Architect*, 88 (January/February 1992): pp. 62-63. cf. Peter Fuller, 'Towards a New Nature for the Gothic.' *Art and Design Profile: The Post Modern Object*, London: Academy Editions, 1987: pp. 5-10.

13 James Gleick, *Chaos: Making a New Science*. London: Macdonald and Co., 1987, p. 117.

14 Gleick, *Chaos: Making a New Science*, p. 117.

15 John Briggs, *Fractals, The Patterns of Chaos: Discovering a New Aesthetic of Art, Science, and Nature* (London: Thames and Hudson, 1992), 70.

16 Briggs, *Fractals, The Patterns of Chaos*, p. 70.

17 Briggs, *Fractals, The Patterns of Chaos*, p. 70.

18 Mandelbrot, *The Fractal Geometry of Nature*. p. 23.

19 Kavannagh, 'Chaos in Architecture.' pp. 62-63.

20 Voss quoted in: Deborah Smith, 'Shaping Up To The Future With Fractals.' *Sydney Morning Herald*. Science supplement, nd. [c1991] unpag.

21 Gleick, *Chaos: Making a New Science*, pp. 116-117. my italics.

22 Friedensreich, quoted without reference in: Peitgen and Richter, *The Beauty of Fractals*, p. v. my italics.

23 Gray, "Critique and a Science for the Sake of Art," p.317.

24 Fuller, "Towards a New Nature for the Gothic.", p. 10.

25 Gray, Noel. "Critique and a Science for the Sake of Art: Fractals and the Visual Arts." *Leonardo*, 24 3 (1991): p. 317.

26 Gray, "Critique and a Science for the Sake of Art," p. 318.

27 Gray, "Critique and a Science for the Sake of Art," p. 318.

28 John D. Barrow, *The Artful Universe: The Cosmic Source of Human Creativity*, London: Penguin, 1995, p. 95.

29 Barrow, *The Artful Universe*, p. 95.

30 Barrow, *The Artful Universe*, p. 95.

31 Barrow, *The Artful Universe*, p.100.

32 Brent C. Brolin, *The Failure of Modern Architecture*, London: Studio Vista, 1976.

33 See: Deyan Sudjic, *The 100 Mile City*, London: Flamingo, 1993.

34 Curiously there is also a subtle nationalist agenda at work in Mandelbrot's architectural examples. It must be remembered that Mandelbrot's works were first published in French language and in Paris and became well known through these editions. The two buildings Mandelbrot repeatedly praises are the *Paris Opera House* and the *Eiffel Tower*-French buildings by French designers. In contrast Mandelbrot criticises the *Seagram Building*; an American building by a German architect.

35 See: Elaine S. Hochman, *Architects of Fortune : Mies van der Rohe and the Third Reich*. New York: Fromm International Pub. Corp., 1990.

36 Barbara Miller Lane, *Architecture and Politics in Germany: 1918-1945*, Cambridge, Massachusetts :Harvard University Press, 1968.

37 Martin Pawley, *20th Century Architecture: A Reader's Guide*. Oxford: The Architectural Press. 2000, p. 58.

38 Peter Adam, *The Arts of the Third Reich*, London: Thames and Hudson , 1990. Michael Z. Wise. *Capital Dilemma: Germany's Search for a New Architecture of Democracy*. New Jersey: Princeton Architectural Press , 1998.

39 Evans, *The Projective Cast*, p. xxvii.

40 Evans, *The Projective Cast*, p. xxvii.