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"Fractal Architecture":

Late Twentieth Century Connections Between Architecture and Fractal Geometry

Michael Ostwald examines the intricate, constantly shifting relationship between architecture and fractal geometry. At times this dependence is diffuse, and modes of theoretical transference are subtle, symbolic or semiological. At other times wholesale appropriations of geometry takes place and large fragments of theory are pirated away from their originating discipline and used opportunistically.

Introduction

For more than two decades an intricate and contradictory relationship has existed between architecture and the sciences of complexity. While the nature of this relationship has shifted and changed throughout that time a common point of connection has been fractal geometry. Both architects and mathematicians have each offered definitions of what might, or might not, constitute fractal architecture. Curiously, there are few similarities between architects' and mathematicians' definitions of "fractal architecture". There are also very few signs of recognition that the other side's opinion exists at all. Practising architects have largely ignored the views of mathematicians concerning the built environment and conversely mathematicians have failed to recognise the quite lengthy history of architects appropriating and using fractal geometry in their designs. Even scholars working on concepts derived from both architecture and mathematics seem unaware of the large number of contemporary designs produced in response to fractal geometry or the extensive record of contemporary writings on the topic. The present paper begins to address this lacuna. Here I focus primarily on architectural appropriations of fractal geometry to briefly describe more than twenty years of "fractal architecture" and to identify key trends or shifts in the development, acceptance and rejection of this concept; the aim is to provide an overview for both architects and mathematicians of the rise and fall of fractal architecture in the late twentieth century. The present paper has three clear limitations or provisions which define its extent and approach. Firstly, it does not question the validity of any specific claims from either architects or mathematicians even though there is evidence to suggest that claims made by both sides are debatable [Ostwald and Moore 1993; 1996a; 1996b; 1997]. Secondly, the paper is concerned only with conscious attempts to use fractal geometry to create architecture. A number of prominent examples of historic buildings that exhibit fractal forms have been proposed by both architects and mathematicians. For the purposes of this paper these proposed fractal buildings, including various Medieval castles, Baroque churches, Hindu temples and works of Frank Lloyd Wright or Louis Sullivan, are not considered to be consciously created fractal designs even if they display an intuitive grasp of fractal geometry. For this reason, the origins of conscious fractal architecture cannot have occurred until after fractal geometry was formalized by Benoit Mandelbrot in the late 1970s even though Georg Cantor, Guiseppe Peano, David Hilbert, Helge von Koch, Waclaw Sierpinski, Gaston Julia and Felix Hausdorff had all studied aberrant or mathematically "monstrous" concepts that are clear precursors to fractal geometry. A final provision for this paper is concerned with the relationship between fractal geometry and the sciences of complexity. While mathematicians and scholars have valued fractal geometry in its own right, architects have generally valued it more for its connection to Chaos Theory and Complexity Science. This is because contemporary architects, like many historic architects, have little interest in geometry or mathematics per se, but value geometry for its ability to provide a symbolic, metaphoric or tropic connection to something else. Thus, for modern architects fractal geometry provides a connection to nature or the cosmos as well as a recognition of the global paradigm shift away from the views of Newton and Laplace. For this reason, the vast majority of architects mentioned in this paper view fractal geometry as an integral part of, or sign for, Chaos Theory and Complexity Science.

The rise of fractal architecture: 1978-1988

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 some sixty-three 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" [Jencks 1987: 9-10] manifest in the demolition of Yamasaki's Pruitt-Igoe Housing in 1972, this birth date 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. Specifically, Mandelbrot concludes his introduction to the book with a discussion of architectural styles in an attempt to differentiate between Euclidean geometry and fractal geometry. In this discussion he states that "in the context of architecture [a] Mies van der Rohe building is a scale-bound throwback to Euclid, while a high period Beaux Arts building is rich in fractal aspects"[Mandelbrot 1982: 23-24]. 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 the attempt to combine or connect architecture with fractal geometry. Less than twelve months after the English language publication of *Fractals: Form, Chance, and Dimension*, the architect Peter Eisenman exhibited his *House 11a* for the first time. A few weeks later, in July of 1978, *House 11a* became a central thematic motif in Eisenman's housing design produced during the Cannaregio design seminar in Venice [Bédard 1994: 54]. Although this project was not publicly exhibited until April 1980, it nevertheless marks the first widely-published appropriation by an architect of a concept from complexity theory.[1] Specifically, Eisenman appropriated the concept of fractal scaling – a process that he describes philosophically as entailing "three destabilizing concepts: discontinuity, which confronts the metaphysics of presence; recursivity, which confronts origin; and self-similarity, which confronts representation and the aesthetic object" [Eisenman 1988: 70]. *House 11a*, a composition of Eisenman's then signature "L"s, combines these forms in complex rotational and vertical symmetries. The "L" is actually a square that has been divided into four quarters and then had one quarter square removed. Eisenman viewed this resulting "L" shape as symbolising an "unstable" or "in-between" state; neither a rectangle nor a square. The three-dimensional variation is a cubic octant removed from a cubic whole, rendering the "L" in three dimensions. According to Eisenman, each "L" represents an inherently unstable geometry; a form that oscillates between more stable, or whole, geometric figures. The eroded holes of two primal "L"s collide in *House 11a* to produce a deliberately scale-less object that could be generated at whatever size was desired. This is exactly what Eisenman attempted for a competition for housing in Venice. His Cannaregio scheme ignored the existing fabric of Venice and sought rather to affirm the presence, or absence, of Le Corbusier's unbuilt hospital plan for the site. Through the creation of a fictional past, a false archaeology, the proposal voids the grid of Corbusier's hospital, leaving absence in place of fictional presence. "These voids act as metaphors for the subject's displacement from its position as the centered instrument of measure. In this project architecture becomes the measure of itself" [Eisenman 1988: 14]. Then Eisenman placed a series of identical objects at various scales throughout the Cannaregio Town Square. Each of these objects is a scaling of *House 11a*, the smallest object being man-height but obviously not a house, the largest object plainly too large to be a house, and the house-sized object paradoxically filled with an infinite series of scaled versions of itself rendering it unusable for a house. The presence of the object within the object memorialises the original form and thus its place transcends the role of a model and becomes a component and moreover a self-similar and self-referential architectonic component [Jencks 1989]. *House 11a* is effectively scaled into itself an infinite number of times forming a kind of fractal architecture.[2] In the twenty years that followed Eisenman's publication of *House 11a* more than two hundred architectural designs or works of architectural theory have been published that have laid claim, in some way, to aspects of fractal geometry or some related area of the sciences of complexity. While Eisenman has produced more than a dozen projects that have relied upon fractal geometry and its characteristics ,a large number of international architects, including Asymptote, Charles Correa, Coop Himmelblau, Carlos Ferrater, Arata Isozaki, Charles Jencks, Christoph Langhof, Daniel B. H. Liebermann, Fumihiko Maki, Morphosis, Eric Owen Moss, Jean Nouvell, Philippe Samyn, Kazuo Shinohara, Aldo and Hannie van Eyck, Ben van Berkel and Caroline Bos, Peter Kulka and Ulrich Königs and Eisaku Ushida and Kathryn Findlay, have followed his lead. Two of Eisenman's projects provide useful points of reference for fractal architecture during this period. Eisenman's 1985 project *Moving Arrows, Eros and other Errors* (or the Romeo and Juliet project) is a turning point in the development of concepts appropriated from Complexity Science into architecture. At the core of the generative methodology underlying this project is the process of scaling [Eisenman 1986]. For Eisenman, fractal scaling confronts "presence, origin, and the aesthetic object" [Eisenman 1988] in the context of the site, the building program and its means of representation. While scaling is already present in various ways in Eisenman's earlier projects, it is in *Moving Arrows, Eros and other Errors* that it takes on a greater importance. Betsky records that by "[u]sing a formula developed by the scientist Benoit Mandelbrot, which determines the 'self-sameness' or autonomous replication inherent in certain figures, [Eisenman] mapped plans of vast territories over each other. This technique questioned architecture's relation to a 'normal scale' and 'problematized' the concept of human perspective" [Betsky 1990: 146].

But why appropriate scaling? The feedback mechanisms and fractal forms associated with order in seemingly chaotic systems are, for Eisenman, a means of destroying the stability of architecture and undermining the anthropomorphic orthodoxy that has sustained architectural theory since Vitruvius. Eisenman argues that,

> *[f]or five centuries the human body's proportions have been a datum for architecture. But due to developments and changes in modern technology, philosophy, and psychoanalysis, the grand abstraction of man as the measure of all things, as an originary presence, can no longer be sustained, even as it persists in the architecture of today. In order to affect a response in architecture to these cultural changes, this project employs another discourse, founded in a process called scaling* [Eisenman 1988: 70].

Moving Arrows, Eros and other Errors is the result of a dual appropriation of fractal scaling and the narrative structure of Romeo and Juliet as drawn from three different versions of the story by Da Porto, Bandello and Shakespeare. The literary narrative is used by Eisenman to dramatise the meeting of the "the 'fictional' and the 'real'"[Eisenman: 71] . In doing so Eisenman attempts to deny the possibility of the origin of a concept meeting reality and thereby destabilize a conventional paradigm in architecture. In the same way he appropriates fractal geometry to undermine the scale specificity of conventional anthropomorphic architecture; another long unchallenged paradigm in architecture. Anthony Vidler suggests that both of these attempts are successful:

In the complex process by which the Romeo and Juliet landscape is generated, there is no sense of an aesthetic or even a natural 'origin' that gives it meaning. Rather, the forms are produced in a seemingly implacable autogeneration of grids, surfaces, and their punctuation that stems from an equally autonomous procedure called by the author 'scaling'. Referring to the random and fractal geometries of Mandelbrot, this method applies a notion of continuum to all scales and all intervals between scales that represent objects in nature, and produces new objects by virtue of their superpositioning … The result is nothing stable, nor anything preconceived; it exists as a complex artifact marked by the traces of the procedures that generated it [Vidler 1992: 130-131].

Perhaps the culmination of Eisenman's fascination with fractal architecture is the project *Choral Works*, which Eisenman designed with the assistance of the philosopher Jacques Derrida. In *Choral Works*, Derrida's seminal text on Plato's *Timeaus* combines with the semiotic play upon Chora, Choral, etc., to create a twin textual and formal (or geometric) example of a fractal *en abime*. In this project, actually not a building but a small garden, both time, in the form of precedents, and space, as a dislocation of Le Corbusier's rediscovered Venetian hospital, are self-referential and are present in a variety of controlled iterations [Derrida and Eisenman 1997].[3] Eisenman claims that

at each scaling [of the design] aspects of the changes in time, changes in rivers, borders, etc. are introduced. Thus reverberations occur not only in scale but in time, resulting in self similar, but not self same analogies. It is as if there were infinite reflections in an imperfect mirror [Eisenman 1988: 137].

Scaling, self-similarity and self-referentiality are all present in *Choral Works* although now these operations have taken on a more philosophical and less geometric presence. *Choral Works* is less obviously derived from geometric iterations than *House 11a* or *Moving Arrows, Eros and other Errors*. It must be remembered that in the late 1980s many philosophers including Gilles Deleuze and Felix Guattari (whose works were becoming widely influential at that time [Deleuze and Guattari 1987; 1994]) had appropriated fractal geometry to explain complex and often unrelated concepts [Sokal and Bricmont 1998]. However, while architects enthusiastically embraced fractal geometry in the early to mid-1980s, this situation was to turn around dramatically in the early 1990s, although signs of a change had started to appear much earlier.

The fall of fractal architecture: 1989-1999

As early as 1988 some architectural writers were deriding their colleagues' obsessions with Chaos Theory, nonlinear dynamics and fractal geometry. At this time, Michael Sorkin, then architectural critic for the *Village Voice*, opens his critique of the work of Coop Himmelblau with an apologetic warning that he intends to resort to a discussion of Complexity Science and fractals. Not only does his manner suggest some latent embarrassment about the topic but he even takes the unusual step of attempting to justify his actions with the claim that they are relevant to the profession – an argument that seems out of context given Sorkin's otherwise aggressive approach.[4] In "Post Rock Propter Rock: A Short History of Coop Himmelblau", Sorkin declares that "[c]haos may be a little overfamiliar nowadays, especially in its studied inscription in architecture. However, the idea behind this latest upheaval in physics does have real implications for us" [Sorkin 1991: 346-347]. Barely two years later, in 1990, Aaron Betsky described Eisenman's Biocentre at the J. W. Goethe University of Frankfurt in terms of a conventional geometric system that is corrupted by fractal geometry. "To safeguard [the] architecture from disappearing completely … Eisenman then meshed fractal geometry with Euclidean geometry, infecting one geometry … with an equally available one" [Betsky 1990: 148]. Here fractal geometry is metaphorically described as a form of virus or parasite inflicting architecture; conventional Euclidean geometry is the antidote. Fractal geometry, the source of the outbreak, is not necessarily critical to the design; rather it is merely the most "available" of a number of possible sources of "infection". The tide had started to turn and the relationship between architecture and the sciences of complexity was now increasingly viewed with cynicism and suspicion. By 1993 a few architects were even starting to deny categorically any connection between their design philosophy, Complexity Science and fractal geometry. For example, Gisue Hariri and Mojgan Hariri, Iranian-born graduates of Cornell University, open their 1993 manifesto for architecture with the statement that "[w]e do not believe in *Chaos*, we do not follow *Trends*, and we despise *Kitsch*" [1993: 81]. By highlighting these three terms in italics, Hariri and Hariri not only emphasize these concepts at the expense of their argument, they also infer that Chaos Theory and fractal geometry are merely a trend that, for them, is equated with kitsch. Once they have carefully distanced themselves from this perceived taint they feel that they can state the theoretical position that governs their design work.

> *It is the intension* [sic] *of our work to bring together in an equilibrium the Mind that disintegrates and categorizes and the Soul that is in constant search for universal unity of all things and events … Examples of this concept The Unification of the Opposites can be found in modern physics at the sub-atomic level where particles are both destructible and indestructible; where matter is both continuous and discontinuous, and force and matter are different aspects of the same phenomenon. Life in general and Architecture in particular are like force and matter intertwind [sic]. It is the events and the smallest experiences in life that form Visions of architecture* [Hariri and Hariri 1993: 81].

It is ironic indeed that the remainder of their philosophical position is derived from a loose understanding of quantum physics, sub-atomic particle theory and natural systems theory [Hariri and Hariri 1993: 118-121; Frampton 1993: 82-83]. Nevertheless, they are not alone in their attempts to deny any connection between their architecture and Complexity Science. Perhaps one of the reasons for this dramatic disavowal might be found in the growing number of satirical descriptions of the relationship between architecture and fractal geometry. Paul Shepheard suggests that in 1994 the constant quest for the new resulted in "a furor of nonconsensus" in architectural theory [Shepheard 1994: 15]. In order to illustrate the confusion of the time he provides five derogatory descriptions of un-named architectural role models. The first description, which appears to be a synthesis of Peter Eisenman, Daniel Libeskind and Morphosis, commences with a veiled insult.

> *Here is a man who scatters chaos on paper and talks about randomness and fractional theory. He calls the scatter the plan of a building. Anything will do – twigs purloined from a pigeon's nest, notes transcribed from the Song of Songs – a scribble he did with his eyes shut, like a shaman in a trance drawing in the dust of the Nevada desert. His building is built. It appears like a mirage in the wasteland of the city, a histrionic essay of joints and*

materials. He claims the building is ambiguous – he says it is like the chaos of modern life – he tells us all that it is profound [Shepheard 1994: 15].

Although Shepheard's description is strongly reminiscent of Sorkin's 1991 critique of the "daffy postfunctionalist methodology (form follows … anything!)" – a design process that culminates in tracing the "outline of last night's schnitzel" [Sorkin 1991a: 111] – it is the way in which the use of fractal geometry in architecture starts to be associated with caricature that is consequential.By the time Alberto Pérez-Gómez presented "Architecture as Science: Analogy or Disjunction" at the 1994 Anyplace conference in Canada, he had to make a deliberate effort to discuss Chaos Theory and fractal geometry as a side-line or accessory to the rest of his presentation on the differences between phenomenological hermeneutics and theories of science. In this way he effectively distances his argument from the taint of nonlinearity while judiciously relying on it to support his position. Pérez-Gómez, realising that what he is about to do is "unfashionable" [Pérez-Gómez 1995: 67], commences his comments on fractal geometry with the informal statement that before progressing to the main theme of the paper he "would like to explore the potentially fascinating consequences of Chaos Theory for architecture. This [being] a popular topic these days" [Pérez-Gómez 1995: 70]. Pérez-Gómez's outline of the paradigm shift associated with Chaos Theory and fractal geometry is an exemplary model of accuracy and scholarship; he has even read the key scientific texts. Yet, throughout the paper, his description is laced with a delicate tracery of sarcasm and wit. Chaos theory embodies "a formidable and exciting realization," he states. "We have at last 'discovered' that the ancient analogical assumptions that drove traditional architecture and science were not merely foolish dreams" [Pérez-Gómez 1995: 70]. Architects are described as playing with these ideas, using them as a form of authority to legitimise their actions and augment their philosophies. "I cherish," he says, "[such] stories about a living world and the life of minerals, about the body without organs, about nature as a machine without parts" [Pérez-Gómez 1995: 70]. The tone of Pérez-Gómez's paper is difficult to dissect. He clearly believes that fractal geometry and Complexity Science have much to offer yet his manner is cynical, or at best, wistful.In the same year, 1994, Christoph Langhof published *Imagination is more Important than Knowledge*, in which he too apologises for lowering the tone of a journal to discuss fractal geometry. "Our world," he says, "– if you would excuse the trendy word – is becoming more and more fractal" [Langhof 1994: 41]. Why would people like Pérez-Gómez and Langhof feel obliged to apologise for discussing geometry? Perhaps the reason may be traced to the rapid growth of interest in complexity. As Paul-Alan Johnson records, Chaos Theory may have only been "formulated in the 1970s" but within a decade it had become "a booming business" world-wide [Johnson 1994: 242]. Yet within architecture, it had shifted smoothly from being the favored theoretical influence of the early 1980s, to being the conceptual bête noire of the early 1990s. When in 1995 Charles Jencks belatedly published a polemical call for architecture to model a new, cosmogenic or fractalesque aesthetic, (a position that he had developed from his study of the sciences of complexity) the critics were sufficiently forewarned that they were able to respond with a flurry of damning reviews.[5] Perhaps this reaction was complicated by the cult of personality surrounding Jencks, or maybe it was justified. But the fact remains that his call for a fractal architecture of complexity was not only savaged by the critics, it appears to have been largely ignored by an architectural profession that now considered fractal geometry dated. From the first recorded reference to fractal geometry in architecture, barely fifteen years had passed before these once-cherished concepts had become anathema. However the cycle from enthusiastic acceptance to almost complete rejection is not complete and signs have begun to appear that suggest that a cautious re-acceptance of complexity is occurring. In 1996 when Carl Bovill published his impressively researched book *Fractal Geometry in Architecture and Design*, a new stage in the ongoing curious and contradictory relationship between architecture and complexity theory was reached. Bovill, more than any other writer in architecture, immerses himself in the mathematics of complexity. He argues that fractal geometry is a powerful tool for architects, but a tool that has to be used wisely. To date, this understated work has been well received, perhaps because its modest aims are well supported in the text. Whether or not Bovill's research signifies a genuine resurgence of interest is unclear at this time. Similarly not all architects stopped designing fractal buildings. Throughout the 1990s the architectural firm Ushida Findlay produced a series of highly inventive projects using golden sections and fractal geometry (often in combination) to generate powerful spatial forms. Their *S Project*, an urban master plan, presents fractal geometry in a particularly compelling manner. The *S Project* is a major transport interchange for Tokyo located at the intersection of a number of arterial roads and a rail line. The design explores the notion of "city as house", an idea given renewed currency by the realization that natural systems posses similar patterns at multiple scales. It is this same realization, that fractal geometry operates at many scales, that is lacking in so many architectural works that claim a fractal heritage. In many ways, because large-scale landscape features are amongst the most recognisable fractal forms, the master plan is an obvious subject for the use of fractal geometry. In the *S Project*, Ushida Findlay are able to propose a fractalesque network that incorporates systems of "flow and clustering" operating simultaneously at many scales. Regardless of whether the design caters to road traffic or pedestrians it provides a system that "can accommodate the innumerable encounters of freely moving persons who drift throughout the city" [Ushida and Findlay 1996]. Ushida and Findlay describe the *S Project* as a vessel designed to accommodate the "Brownian movement" of people, cars, trains and information. The result is "a new terrain – a new kind of topography" that possesses dynamic similarities at many scales [Ostwald 1998: 136-143].

Conclusion

For almost twenty years there has existed an intricate, constantly shifting relationship between architecture and fractal geometry. At times this dependence is diffuse, and modes of theoretical transference are subtle, symbolic or semiological. At other times wholesale appropriations of geometry take place and large fragments of theory are pirated away from their originating discipline and used opportunistically. As Peter Downton evocatively suggests,

> *... [on] dark nights knowledge is sometimes smuggled over the difficult terrain at disciplinary borders by radical thinkers. It is urgently introduced in clandestine meetings and infiltrated by stealth into the mainstream of the discipline without the blessing of the powerful upholders of conventional orthodoxy, the high priests of the dominant paradigm* [Downton 1997: 82].

At other times analogies are drawn, both by mathematicians and by architects, that call upon the opposing body of theory to submit to an array of duties, ranging from menial, pedagogical roles to heroic, evidential ones. Throughout the period of this interdisciplinary relationship few from one side have commented on the other side's position. That is, few architects have discussed the way in which architecture is used by scientists and mathematicians working in the sciences of complexity, and conversely, even fewer scientists or mathematicians have noted the way in which architects borrow scientific or geometric theories from complexity. A small number of architectural writers, including Peter Fuller, Charles Jencks, John Kavannagh, Paul-Alan Johnson and Norman Crowe[6] are clearly aware that another side of the relationship exists, that mathematicians have made incursions into architecture.[7] But only Pérez-Gómez has even obliquely considered this relationship in a critical sense, concluding deftly that "Mandelbrot's view [of architecture] is hardly different from Prince Charles's opinion" and that "the relationship between geometry and architecture imagined by Mandelbrot and some of his architectural fans is thoroughly classical, simply mimetic in the traditional sense" [Pérez-Gómez 1995: 72]. Examples of the obverse case, that is, mathematicians realizing that architecture has appropriated from fractal geometry, are even more uncommon. Only the scientist Peter Coveney and the journalist Roger Highfield seem to be aware of, or willing to remark on, the fact that architects are developing their own interpretations of Complexity Science and fractal geometry. In a brief survey in their 1996 book *Frontiers of Complexity, the Search for Order in a Chaotic World*, Coveney and Highfield comment on developments in the non-scientific fields that have arisen from a study of complexity. They state, with some consternation, that "[c]omplexity has offered a 'cosmogenic' cocktail – the motifs of fractals, catastrophic theory, and chaos – that has caught the imagination of architects" [Coveney and Highfield 1996: 339]. Their promising footnote leads only to Jencks's *The Architecture of the Jumping Universe*; a minimal recognition but nevertheless better than any other.[8] These fragments of history are pieced together here to give a brief overview of the often tortuous alliance, the sporadic shifting from amour to intrigue, that has characterized the relationship between architecture and fractal geometry for more than twenty years. The simple reconstruction offered here, while representative of the major shifts in the relationship, is necessarily superficial. Not all architects turned away from fractals in the early 1990s and, in the last five years, the signs of renewed enthusiasm for complexity are chimerical at best. In time it might be possible to tell which way the relationship will shift. Whether or not it will mature and stabilize (the state wherein cross-appropriation is mutually recognized) remains largely unclear. Similarly, while this general history, which is woven from fragments, records a reasonable overview of the changes that have occurred, it can not and will not suffice to explain all of the roles that fractal geometry has been forced to play in architecture, or architecture in fractal geometry.

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Notes

1. In *Violated Perfection*, Betsky incorrectly refers to Eisenman's "Romeo and Juliet" project, *Moving Arrows, Eros and other Errors*, as being produced in 1976. If this date were correct it would make the "Romeo and Juliet" project the first instance of an architectural appropriation from chaos theory, some twelve months before the English publication of *Fractals: Form, Chance, and Dimension*. The real date of the exhibition of *Moving Arrows, Eros and other Errors* is 1986, thereby confirming Eisenman's *House 11a* (or the contemporaneous design for Cannaregio housing) as the first widely published instance of an architectural appropriation from chaos theory. Cf. [Betsky 1990: 146; Eisenman 1986].
2. When examined in detail, from a scientific perspective, the concept of "fractal architecture" is problematic. See [Ostwald and Moore 1996c].
3. It should be noted that Eisenman variously calls the project *Choral Works* or *Chora l works* (the latter being a Greek pun). *Choral Works* is usually the correct title for the project. Kipnis uses the pun instead as a title for the book (not the project) because the book looks at Greek philosophy as well as Eisenman's project.
4. Ironically, as Jencks notes in a 1996 interview with the author of this paper, Sorkin, who has expressed his reluctance to affix the label of chaos theory on any work of architecture for fear that it might be read as over fashionable, should himself by 1993 be producing designs that are in part inspired by his readings in complexity. Jencks states that "it is completely and utterly rich that someone like Michael Sorkin, who is now seven years later designing chaos cities, is claiming that it is out of date. He should have had a little more insight into himself,

than to have denigrated the idea in other peoples work and then done it. Come on—*Mea Culpa*. Often the people who damn fashion are those who are about to be victims of it …" Cf. [Ostwald, Zellner and Jencks 1996: quote on p. 29].

5. See, for example, the following critiques: Peter Davey, "The Architecture of the Jumping Universe" (Review) *GSD News* (Harvard University, Graduate School of Design) (Fall 1995): 40-41; Peter Davey, "The Scientific American", *Architectural Review* **198**, 1183 (September 1995): 84-85; Christian Norberg-Schulz, "The Jumping Jencks," *Byggekunst: The Norwegian Review of Architecture* **77**, 7 (1995): 399; Giles Worsley, "The Architecture of the Jumping Universe," *Perspectives on Architecture* **2**, 15 (July 1995): 18; Richard Weston, "A New Architectural Style is Born-Again," *Architects' Journal* **201**, 21 (May 25, 1995): 52.
6. The architectural historian Crowe discusses Mandelbrot's views on architecture in some detail as a means of explaining a different way of appreciating patterns at multiple scales. Crowe mostly reiterates Mandelbrot's assertions for architecture without comment although he finally concludes that for Mandelbrot "the presence of a natural sense of visual detail that relates to scale may well explain why such buildings as prismatic glass skyscrapers soon become boring to many people. This insight might also be considered for our negative reaction to a building or interior that has too much ornament and so appears to us as chaotic". Cf. [Crowe 1995: 119].
7. Two papers by the author with R. John Moore are, to date, the most detailed works on the topic. See [Ostwald and Moore 1995; 1997b].
8. In *Fearful Geometry* [1993], Stewart and Golubitsky also comment on appropriations from mathematics by architects but they are talking about Euclidean geometry not fractal geometry.

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