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Influences and changes in the architectural space of the early twentieth century and their relation to a Kuhnian paradigm shift in architecture

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Influences and Changes in the Architectural Space
of the Early Twentieth Century
and Their Relation to a Kuhnian Paradigm Shift in Architecture

by

Patricia van Horn

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IN PARTIAL FULFILLMENT OF THE
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ABSTRACT

Influences and Changes in the Architectural Space of the Early Twentieth Century and Their Relation to a Kuhnian Paradigm Shift in Architecture

by

Patricia van Horn

Changes in architectural space which occurred at the beginning of the century are investigated to determine whether or not they represent a single, unified event. As examples of these changes, the work of three architects who were largely responsible for changes in the perception of space (Frank Lloyd Wright, Le Corbusier and Theo van Doesburg) are studied. The influences on the formation of their views are evaluated relative to the larger changes in space perception which occurred in other fields.

The results are then studied to determine to what extent they can or cannot support an application of Kuhn's Theory of Paradigm Shifts to the field of architecture. A comparison of these influences indicates that the changes do not represent a single, unified event but rather arose from different influences and for different reasons. The results, therefore, do not support an application of Kuhn's theory for changes in architectural space.
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Shishe
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"A great deal of cant is talked nowadays about space in architecture, but behind the extravagant phrases and recondite terms one indisputable fact emerges; namely, that architects today consider that modern buildings possess spatial relationships of quite a different order from those possessed by the buildings of the past. There are even some theorists who contend that this new attitude towards space constitutes the basic principle which distinguishes the style of the modern age." [My Italics.]

-- Peter Collins, 1965

INTRODUCTION

Remarks such as those by Peter Collins on the nature of modern architecture have caused many to view the changes in the perception of architectural space as a unified event. To some historians, such as Sigfried Giedion and Bruno Zevi, the perceived changes appeared so significant that architectural histories were rewritten as the histories of architectural space. It is almost impossible to deny that some change in space perception in architecture occurred, but before one can make definitive statements about such a unified event, the event must be explored more closely.

There is no question but what there was a change in the way architects represented space during the first decades of the twentieth century. Rooms enclosed by four walls gave way to larger volumes of space whose boundaries were less well-defined or overlapped and intermingled with other spatial volumes. These volumes were sometimes clearly enclosed within the building envelope and at other times were allowed to flow beyond the envelope and out into space.

During this time, the vocabulary of architecture changed as well. Architect moved away from speaking about "rooms" and "walls" and began to speak of "volumes," "planes," and "masses." Cantilevered roofs and balcony slabs extended planes, and the
spatial volumes they defined, out beyond the walls of the building and into space. One of the De Stijl architects, J. J. P. Oud, remarking on Frank Lloyd Wright's influence in European architecture in 1925 referred to the "shifting of planes" and "the repeatedly interrupted and again continued masses" of his work.²

What makes this period especially interesting to study are the other significant shifts in thinking which occurred almost concurrently. The Cubist and Futurist movements in art were experimenting with different representations of space and the inventions of the period (i.e., the telephone and the automobile) were causing many to rethink their understanding of space and time. Most significant of the events of the early twentieth century, however, were the changes in the perception of space and time in science. As a result of the work of many, but culminating in the work of Albert and Einstein, came the dissolution of absolute space and absolute time.

Given that such a significant change in the perception of space occurred within architecture and many other disciplines, one must ask to what extent these changes in architecture may be viewed as a unified redefinition of space within architecture caused by common influences within the discipline, and to what extent they may be seen as a direct result of changes happening in other disciplines.

In order to examine more closely these questions, the change in space perception of three architects, who were influential in changing the perceptions of space in architecture, will be evaluated to determine whether or not common links or common perceptions can be found: Frank Lloyd Wright, Le Corbusier and Theo van Doesburg. Each was born between 1869 and 1887 and practiced during the turbulent years of the early twentieth century.

Because these changes have been seen as such a decisive shift in architectural space, and because it happened concurrently with the scientific revolutions of Einstein and quantum physics, the results of this investigation will then be applied to Thomas
Kuhn's model of scientific development to determine to what extent the changes in architectural space can be viewed to support a similar model for architectural change. Though written well before Kuhn's 1962 book, *The Structure of Scientific Revolutions*, Sigfried Giedion wrote an architectural history based on the primacy of space which closely parallels the tempo and mode for change suggested by Kuhn. One must then ask the question whether or not the events of the early twentieth century support the argument that a paradigm shift in architectural space occurred at the beginning of this century.

The results of this research indicate that, while Wright, Le Corbusier and van Doesburg did develop new conceptions of space, they developed different kinds of architectural space and did so from different influences. Their developments do not, therefore, represent a unified attempt to redefine architectural space. In comparing these results with Kuhn's theory, one finds at one level a possible fit with the behavior of a pre-paradigmatic stage, but upon further investigation into Kuhn's definition of a paradigm, one must question whether space is sufficient as a basis for an architectural paradigm.
THE TURMOIL OF THE EARLY 20TH CENTURY

The coincidence of major shifts in the perception of space and time in several disciplines during the turn of the century has been noted by many historians. In the introduction to The Culture of Time and Space 1880-1918, Stephen Kern began:

"From around 1880 to the outbreak of world War I a series of sweeping changes in technology and culture created distinctive new modes of thinking about and experiencing time and space. Technological innovations including the telephone, wireless telegraph, x-ray, cinema, bicycle, automobile, and airplane established the material foundation for this reorientation; independent cultural developments such as the stream-of-consciousness novel, psychoanalysis, Cubism, and the theory of relativity shaped consciousness directly. The result was a transformation of the dimensions of life and thought."3

The changes, as Kern noted, included the popularization of inventions which allowed the public to defy their previous understanding of time by using a phone (to eliminate the time it would have taken to travel to see a person), or by using a car, bicycle or airplane to visit a person at unheard of speeds. In addition, however, there were much more
fundamental changes to our world perception which affected a great number of disciplines. Psychology was rewritten by Sigmund Freud, painting rejected Renaissance perspective, and as we have noted, science destroyed the concept of absolute space and time.

Salomon Bochner, a noted mathematician, was in the process of writing a book about this incidence when he died. The working title of his book, *Kepler, Einstein, Spengler: The Role of Space in Nature and Knowledge*, indicated not only the crossover between disciplines, but also the importance of the role of space in these advancements. In the preface to the second version of his draft, dated March 25, 1980, Bochner made a list of the intellects that he felt peaked in the time between 1910 and 1919. The list, after Einstein, was as follows:

"Sigmund Freud -- Totem and Taboo
Spengler
Picasso of Cubism
Franz Kafka
Lenin
Woodrow Wilson
Carl Jung
Arnold Schoenberg
Max Weber
Marcel Proust
James Joyce
Theodore Dreiser
Bertrand Russell
A.N. Whitehead of Principia mathematica
Ludwig Wittgenstein."

This list covered a wide variety of disciplines -- the literature of Kafka, Proust, Joyce and Dreiser; the politics of Lenin and Wilson; the psychology of Freud and Jung; and the atonal music of Schoenberg, to name only a few. By expanding the frame of reference to include the first two decades, one must add many more names to the list. These include the mathematics of Hermann Minkowski, the art of Umberto Boccioni and the Futurists,
the early architectural stages of Frank Lloyd Wright and Le Corbusier, and the work of Theo van Doesburg and De Stijl. [See the timeline in Appendix A.]

The changes which took place in different disciplines were not all about new conceptions in space. Kern's work tried to deal with the entire phenomenon of change in space and time. Other works, such as Linda Dalrymple Henderson's *The Fourth Dimension and Non-Euclidean Geometry in Modern Art* and Leonard Shlain's book, *Art & Physics: Parallel Visions of Space, Time and Light*, concentrate more specifically on the relationship between the visual arts and physical sciences.

While Kern's work dealt specifically with the phenomenon of changing perceptions in space and time during this era, histories which correlate the developments in architecture throughout history with changing perceptions of space have been written in this century by Paul Frankl (1914), Sigfried Giedion (1941), Bruno Zevi (1957) and Cornelis van de ven (1977). This thesis is an attempt to look at the outside influences which affected changes in architectural space perceptions, specifically during the early twentieth century. It is not an attempt to establish all of the interconnections which exist between the different disciplines and personalities, but is only to establish what lines of thought contributed to the spatial changes which occurred in architecture at the beginning of this century and whether or not these spatial changes appear to be unified.
THE IMPORTANCE OF SPACE IN ARCHITECTURE

 Particularly during this century, the role of space has played an increasingly significant role in architectural histories. Following in the footsteps of his mentor, Heinrich Wölfflin, Sigfried Giedion wrote one of the most popular architectural histories based on the changing conceptions of space. The title of his book, Space, Time and Architecture, and a section in the introduction on the "unconscious parallelisms of method in science and art" make it clear that his history is bound up with the recent formulation of space-time. In that part of his introduction entitled "Procedures," Giedion explicitly divided the periods of architectural history into periods corresponding to the divisions in the changing conception of space. In Giedion's introduction to the fifth edition (1967), he was much more specific about the importance of space in architecture:

"It is not the independent unrelated form that is the goal of architects today but the organization of forms in space: space conception. This has been true for all creative periods, including the present. The present space-time conception -- the way volumes are placed in space and relate to one another, the way interior space is separated from exterior space or is perforated by it to bring about an interpenetration -- is a universal attribute which
is at the basis of all contemporary architecture." [My italics.]

Bruno Zevi's account of architectural history, *Architecture as Space* also states the importance of space in architecture:

"The history of architecture is primarily the history of spatial conceptions. Judgment of architecture is fundamentally judgment of the internal space of buildings."6

Later in his book, having evaluated the other interpretations one could use to evaluate architectural history, he responded with an argument which implied an objectivity the other interpretations could not give:

"Interpenetrating space consequently means including all the realities of a building. Every interpretation that does not start with space is constrained to establish that at least one or another aspect of architecture is valueless, and so leaves it out, choosing, *a priori*, a corner of the field on which to concentrate."7

Through the work of the three architects to be discussed we will see that while space does play an important role in architecture, it is only a tool for the realization of other ideas about architecture.
THE SPACE OF FRANK LLOYD WRIGHT

A demonstration of the extent to which Frank Lloyd Wright's representation of space in architecture changed is reflected in the progression seen in three of his early works, the W. H. Winslow house (1893-94), the Emma Martin house, also known as the Frick-Martin house (1901, altered in 1907), and the Robie House (1908). Through this progression, one notes the movement away from a single solid volume, to the articulation of solid volumes, and finally to the interpenetration and extension of spatial volumes.

The Winslow house, Wright's first house designed independently, was very traditional in the way in which it dealt with space. The plan (1) shows that the rooms were designed as separate elements, with limited openings from one room to the next. The overall footprint is rectangular, except for the extension of two bays, one for the conservatory and the other a living room window seat. The elevation (2), though geometric for its time, retains a flat surface. One can see the first attempts at the horizontality found in his later works in the decoration on the second-story frieze. The accentuated entry acts both to express the interior volume behind the entry and to pull the exterior entry plaza into a three dimensional volume. In this building, one sees little indication of the spatial changes which were later to occur in his work.
Figure 1 -- The W. H. Winslow House, River Forest, Ill. by Frank Lloyd Wright. (From A Testament by Frank Lloyd Wright, page 27.)
Figure 2 -- The W. H. Winslow House, River Forest, Ill. by Frank Lloyd Wright. (From The Early Work by Frank Lloyd Wright, page 18.)
In the following decade, however, Wright began to articulate spatial volumes more clearly both in plan and in elevation. A view of the Emma Martin house, built in 1901 and altered in 1907 (3), is immediately striking because of the clarity with which he dealt with these spatial volumes. One reads the building as a construction of rectangular solids. This is particularly emphasized by the window openings which appear to be rectangular volumes removed from the solids. In plan (4), the spaces are also freer than in the Winslow house. The living room (Wohnzimmer) can be read as an overlap of two or three rectangular spaces. It can either be seen as a long axial space centered around the fireplace with two side bays, or as a wider room with an end extension for reading. The footprint of the building also no longer conformed to a rectangular layout and the thickened walls on the rear facade created a double reading for the spatial organization of the interior. Of this house, Joseph Connors wrote:

"Each large component of the house is designed in strict symmetry, but the components are allowed to combine in a fluid way. It is as though the laws of physics had been momentarily suspended so that one solid mass could interpenetrate another until at a certain point these laws were suddenly reasserted and the drifting masses locked into place."\(^8\)

The full expression of this new spatial understanding can readily be seen in the Robie house of 1908. No longer are the volumes expressed as interlocking solids, but now as interlocking spaces. In plan (5), the terrace, living room and dining room are read as independent rooms or, alternately, as one continuous, flowing space. This unity is accomplished by the passage spaces on either side of the fireplace. The living room and dining room are simultaneously viewed as being part of an extended axis out through the terraces and as part of a larger volume defined by the two interior rooms and the front flower garden. The long cantilevers and the extensive use of glazing dissolve the solidity
Figure 3 -- The Emma Martin House, Oak Park, Ill. by Frank Lloyd Wright. (From The Early Work by Frank Lloyd Wright, page 72.)
Figure 4 -- The Emma Martin House, Oak Park, Ill. by Frank Lloyd Wright. (From The Early Work by Frank Lloyd Wright, page 73.)
of the volumes seen in the Emma Martin House. (6,7) This final move which freed the spatial volumes from their solidity allowed the volumes to flow out beyond the building toward the horizon.

In the spatial development of Wright, there is a definite trend away from the containment of spatial volumes within the building envelope. The use of larger areas of glazing, and in particular the glazed corners for which he was known, and the cantilevered roof planes first shown in the Robie house allowed a viewer inside to feel as though they were inside a much larger "room" which continued on outside the building. This type of space and spatial continuity was quite different from the architectural spaces of the nineteenth century.
Figure 5 -- The Robie House, Chicago, Ill. by Frank Lloyd Wright.
(From A Testament by Frank Lloyd Wright, page 76.)
Figure 6 -- The Robie House, Chicago, Ill. by Frank Lloyd Wright.
(From The Wendigen edition, page 27.)
Figure 7 -- The Robie House, Chicago, Ill. by Frank Lloyd Wright.
(From The Robie House by Joseph Connors, page 3.)
THE SPACE OF LE CORBUSIER

In the case of Le Corbusier, the architect is much more interested in the purity of spatial volumes than in the flow of spaces beyond the building envelope. Born eighteen years later than Wright, in 1887, Le Corbusier completed his first architectural work only one year before the construction of Wright's Robie house. This first project was built while Le Corbusier was still using his given name, Charles-Édouard Jeanneret, and under the guidance of his mentor, L'Eplattenier. The Maison Fallet, 1907 (8), is typical of the three early works he did in La Chaux-de-Fonds in 1907 and 1908. It is not typical of his later works. The Maison Fallet is traditional in appearance, looking very much like other villas of the area. Unlike his later work, his early houses maintained the pitched roofs of the region, kept within the traditional building footprint, and used decoration on the building's exterior, something he later abandoned.

By 1927, Le Corbusier presented a much different understanding of space in architecture as represented in the Villa Monzies-Stein at Garches. From the exterior, he orchestrated the facades in such a way that one can read independent but overlapping volumes simultaneously. The garden facade is the most expressive view of this new representation of space. (9) An observer can read both a horizontal volume on the
Figure 8-- Maison Fallet, La Chaux-de-Fonds, France. by Charles-Édouard Jeanneret. (From Le Corbusier: Ideas and Forms by William J. R. Curtis, page 21.)
second floor contained between the second and third floor slabs and an alternate, vertical volume bounded by the two walls which extend beyond the roof terrace. A similar simultaneity of space is noticed on the front elevation (10) as an observer can read a continuity between the central opening on the ground floor and the protruding balcony on the third floor. There is an implied volume which one assumes to run behind the front facade which in reality does not exist, but the duplicity in reading creates a much richer and different spatial understanding than one sees at Maison Fallet.

The resultant architecture has a much different reading of space, as Colin Rowe described in "Transparency: Literal and Phenomenal:"

"The reality of deep space is constantly opposed to the inference of shallow; and, by means of the resultant tension, reading after reading is enforced. The five layers of space which, vertically, divide the building's volume and the four layers which cut it horizontally will all, from time to time, claim attention; and this gridding of space will then result in continuous fluctuations of interpretations."

One sees in the plan (11) an even greater difference in the concept of space. Here open, flowing spaces, particularly on the first and second floors, allow an observer to read the floor planes as a datum against which one reads pure spatial volumes created by openings between floors. Here, three pure volumes are contained within the rectangular building envelope and thus create a very different new conception of space than that of Wright. The interpenetrations of space represented in Le Corbusier's work is much different than the expression of space represented in the Robie house. Where Wright allowed his spatial volumes to breach the building envelope, flowing freely from inside to outside, Le Corbusier's spaces were volumes, interconnected and overlapping, but contained and read through the exterior surfaces.
Figure 9 -- Villa Monzies-Stein at Garches, south garden facade, by Le Corbusier.
(From Le Corbusier: Ideas and Forms, by William J. R. Curtis, page 83.)
Figure 10 -- Villa Monzies-Stein at Garches, front facade, by Le Corbusier.
(From Le Corbusier My Work, translated by James Palmes, page 77.)
Figure 11 -- Villa Monzies-Stein at Garches, plans, by Le Corbusier. (Original illustration.)
THE SPACE OF THEO VAN DOESBURG

Theo van Doesburg was by far the most radical in terms of his rethinking of ideas about space. As an architect, van Doesburg produced little but was very influential in theory and through his involvement with, and founding of, De Stijl. In 1912, his tastes concerning art were "very conservative" and his own art reflected it. His work, as reflected in the work Petite paysanne hollandiase, (12) painted in 1913, at that time leaned toward impressionism, but still showed a traditional understanding of space.

By 1917, a very different type of work had emerged. In his paintings, and stained glass, he had begun to experiment with the solid rectangles of color of Piet Mondrian, and moved away from representational art. (13) His unbuilt architectural projects designed with Cornelius van Eesteren show a development of this technique in three dimensions. In one of their projects for a private house of 1923, the floor plans (14) show a free arrangement of spaces, which overlap and extend out into space. Though one can read solid volumes in the photo and axonometric drawing of the project (15, 16), the balconies and varied roof levels create a group of objects which appear to float in space. The irregularity of these solids also allows one to read overlapping and interpenetrating spaces.
Figure 12 — *Petite paysanne hollandaise*, 1913, by Theo van Doesburg.
(From *De Stijl: The Formative Years, 1917-1922*, by Carel Blotkamp, page 5.)
Figure 13 -- *Composition IX, The Cardplayers*, 1917, by Theo van Doesburg. (From *Theo van Doesburg*, by Joost Baljeu, page 26.)
Figure 14 -- Private house design, 1923, by Theo van Doesburg and C. van Eesteren. (Original drawings based on Theo van Doesburg, by Joost Baljeu, page 60.)
Figure 15 -- Private house design, 1923, by Theo van Doesburg and C. van Eesteren. (From *Theo van Doesburg*, by Joost Baljeu, page 61.)
Figure 16 -- Private house design, 1923, by Theo van Doesburg and C. van Eesteren. (From De Stijl, by Hans L. C. Jaffé, page 175.)
Van Doesburg's true intention with the private house project is made clearer by his painting of it a year later entitled *Colour Construction in the fourth dimension* *space-time*. (17) In this image, the extraneous walls have been removed in order to allow one to view what he considered to be the essential planes of the project. Perhaps the reason he built few projects was because physical structures required of a building (enclosure and protection from the elements) could not support the gravity-free nature of the project he intended.

His writings, which influenced a large group of artists and architects in De Stijl, made it clear that he sought a much freer approach to the representation of space. In "The New Aesthetics and Its Realization" (1922), van Doesburg wrote: "To think of architecture as a pile of boxes is, to put it mildly, a 'superficial' approach." Later clarifying and expanding on this position, in "Towards Plastic Architecture" (1924), he made the following points:

"2. The new architecture is *elementary*, which signifies that it develops from the elements of construction as understood in the most comprehensive sense. These elements are for example, function, mass, plane, time, space, light, colour and material, and they are, moreover, also *plastic elements*....

5. ...The division of functional space is strictly determined by rectangular planes which possess themselves no individual shapes, since, although defined (one plane by the other), they can be extended infinitely by the imagination....

11. The new architecture is *anti-cubic*, which specifies that it does not attempt to combine all functional space-cells into one closed cube, but *projects the functional space-cells* (as well as overlapping planes, the volumes of balconies and so forth) centrifugally, or from the core of the cube outward, thereby giving a completely
new plastic expression in open space to the dimensions of height, width, depth+time.\textsuperscript{13}

The effects of such influence in built architecture can be seen in the Schröder house by Gerrit Rietveld also designed in 1924. (18) One can see in this work the direct influence of the idea of creating spaces with planar elements. This is particularly obvious in the balcony detail shown. Here, the balcony is comprised of two intersecting planes. Part of the balcony is protected by a vertical plane floating in space and part of the balcony space is allowed to continue beyond because of the minimal detailing of the handrail. This house is meant to be read as a habitable area created by the intersection of a number of planes floating in space.

The architectural spaces proposed by van Doesburg and built by other members of De Stijl represent yet another concept of space. In this case, the volumes expand beyond the horizontality of Wright and the envelope of Le Corbusier. They are to be created from planes which can be extended by the mind. They are to embody Space and Time.
Figure 17 -- Colour construction in the fourth dimension of space-time, 1924, by Theo van Doesburg. (From Theo van Doesburg, by Joost Baljeu, page 143.)
Figure 18 -- The Schröder House, Utrecht, 1924, by Gerrit Thomas Rietveld.
(From De Stijl, by Hans L. C. Jaffé, page 193.)
THE CHANGING PERCEPTIONS OF SPACE AND TIME

We have seen from the preceding examples that there was a significant change in architectural space among these three architects and theoreticians of the period. One is then led to ask the question whether they sought new representations of space for similar reasons and whether or not they reached their conclusions from the same or different influences. There was, as we have noted, a significant rethinking of space in a number of fields. In Science, this culminated in the Einsteinian and quantum physics revolution which brought about the destruction of absolute space and time and replaced it with a reality in which space and time are relative.

Before examining the stated reasons and influences which led to the individual investigations of architectural space by the three individuals being studied, it is necessary to understand the development of the ideas about space which had been developing during the nineteenth century. In order to determine to what extent changed space perceptions in architecture derived from the debates of the day, one must attempt to understand the dynamics of their investigations. As we shall see, some of the developments came from inquiries into specific questions about space and time, while others came from the imaginative application of some of these ideas.
MATH

The first hints of the changing perception of space came within mathematics early in the nineteenth century. The culmination of events in mathematics came in 1908 when Hermann Minkowski, having read "The Special Theory of Relativity" by his former student, Albert Einstein, coined the "space-time continuum," which stated that "henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." Much as there was an outcry in architecture calling for architectural change long before that change occurred, Minkowski and Einstein's revelations were not without their precursors. Early in the nineteenth century, mathematicians and physicists began to explore alternatives to the concept of Euclidean geometry, but their efforts remained in the realm of the hypothetical and rarely reached the lay public until the events of the early twentieth century.

Prior to the nineteenth century, the premises of Euclidean geometry had gone unquestioned. Euclidean geometry is a flat geometry in which the shortest distance between two points is a straight line. In such a geometry, the sum of the angles of a triangle equal 180 degrees. In an attempt to see if the space in which we live is indeed Euclidean, mathematicians such as Carl Friedrich Guass began to measure the angles of large triangles to see if they added up to 180 degrees. Gauss attempted to do this by measuring the triangles formed between mountain peaks. Though Gauss and his colleagues failed to disprove the Euclidean nature of the geometry of the universe, he pointed the way for future investigations.

Independently, Nicolai Lobachevsky reached similar conclusions as to the possibility of non-Euclidean geometry less than fifteen years later. Basing his work on the conclusion that in Euclidean geometry two parallel lines can never intersect (derived from Euclid's fifth postulate), he attempted to measure the parallax between distant stars.
in order to validate the existence of non-Euclidean geometry in nature. His efforts also failed to reach a positive conclusion.

It was Bernard Riemann's work, continued upon the foundations of Gauss, his former teacher, that non-Euclidean geometry found its most convincing spokesman and began to gain attention. In 1854, Riemann gave a lecture in which he proposed that, rather than being flat, it is possible that space is curved. This curvature has two implications: first, that two parallel lines can intersect, and second, that if one were to travel in a straight line, one would eventually return back to where one began. This idea was fairly easy to visualize since the surface of the earth behaves exactly the same way relative to our limited perception. In this geometry, the shortest distance is not a straight line, but rather an arc, much as we must travel a curved path, along the curvature of the earth, when we wish to reach a distant destination.

More than anything, Riemann's lecture in 1854, subsequently published in 1867, allowed mathematicians and scientists to seriously considered the possibility of a new perception of space. According to Max Jammer:

"With the new discovery of non-Euclidean geometry it became clear that there were no a priori means of deciding from the logical and mathematical side which type of geometry does in fact represent the spatial relations among physical bodies." 16

Though for the most part none of these theories made it into popular public knowledge until after the turn of the century, they were important to later changes in the way in which we perceive space. For Einstein, Riemann's concept of a curved space was critical to the completion of the relativity theory.

Henri Poincaré's work on the measure of time was also valuable to Einstein's work on relativity. Poincaré's most notable article, "La Mesure du Temps" appeared in
1898 and called into question the absolute nature of time. In the essay he wrote, "we have no direct intuition about the equality of two time intervals. People who believe they have this intuition are the dupes of an illusion." Poincaré's biggest contribution according to Alexander Pais, a biographer of Albert Einstein, was his questioning of absolute simultaneity. Events which appear to be simultaneous from one particular vantage point, may not be simultaneous in their occurrence. (Take, for example, two lovers embracing under a shooting star -- the actual event of the shooting star is not simultaneous with the embrace but only appears to be so given the amount of time it has taken for the light of the event to reach the two lovers.) Henderson claims that Poincaré, "more than any individual, was responsible for popularization of non-Euclidean geometry in Paris during the first decade of the twentieth century." In addition to his questioning of simultaneity,

Poincaré was also well-known for his argument that it is impossible to either prove or disprove whether the geometry of the world was in fact Euclidean. His argument, which was particularly fascinating to non-scientists, was that there was no way of knowing whether or not we live in a Euclidean world. In the event that the sum of the angles of a large triangle were to deviate from 180 degrees, one could argue proof that the universe is non-Euclidean, or one could simply argue that light waves do not travel in a straight line. There would be no way of determining which of the two statements was true.

Just as important as the non-Euclidean theories which were starting to appear were the theories of possible other dimensions. Prior to these thoughts, the universe had been thought to have had only three dimensions -- length, width, and height. Though n-dimensional theory started to make an appearance in the sciences and in philosophy at the end of the nineteenth century, it is in literature that one finds understandable and popular expression of these ideas.
LITERATURE

Among the most popular of the tales in literature to visibly distort our perceptions of space and time were Lewis Carroll's two books, *Alice's Adventures in Wonderland* (1865) and the continuation, *Through the Looking Glass* (1872). These stories were of great popularity and allowed the ideas of a distorted perception of space and time to enter the public realm. In her adventures, Alice's perceptions of space and time are called into question because she was able to change her own size by ingesting part of a mushroom and met a rabbit in *Through the Looking Glass*, who exclaimed, "The faster I go, the behinder I get." These adventures carry even more significance for their distortion of space and time because they are written under a pen name by a mathematician, Charles L. Dodgson, someone who was aware of the debates of the day.

There are many other instances in literature during the nineteenth century which began to question our traditional understanding of space and time. Edgar Allan Poe may have been the earliest in literature to find words for the interconnectedness of space and time when, in his essay *Eureka* (1846), he wrote: "Space and duration ARE ONE." The most complete description of the idea of a fourth dimension, however, came from a theologian and philosopher, Edwin A. Abbott, who wrote *FLATLAND: A Romance of Many Dimensions* in 1884. It went through a second printing in the year of its publication and had undergone fifteen printings by 1915.

This book dealt specifically with an inhabitant of a two-dimensional universe, the Square. During the course of the Square's description of Flatland, he is visited by a Sphere from Spaceland. Moving through the plane of Flatland, the Sphere is first seen as a point, then a small circle which grows and then diminishes in size, until it is once again a point. As the Sphere moves back up through Flatland, the Sphere bumps the Square
into the higher realm of Spaceland. Upon seeing Flatland from a third dimension, the Square begs of the Sphere to take him to even higher realms:

"My Lord, your own wisdom has taught me to aspire to One even more great, more beautiful, and more closely approximate to Perfection than yourself. As you yourself, superior to all Flatland forms, combine many Circles in One, so doubtless there is One above you who combines many Spheres in One Supreme Existence, surpassing even the solids of Spaceland. And even as we, who are now in Space, look down on flatland and see the insides of all things, so of a certainty there is yet above us some higher, purer region, whither thou dost surely purpose to lead me ..."  

The analogy described makes it easy for one to visualize the existence of a fourth dimension beyond our own three dimensions. The popularity of the book in England and the United States was matched by its popularity in France. According to Linda Dalrymple Henderson, even though the book was not translated into French, it was known in Paris. E. Jouffret mentions Abbott's work in his 1903 *Traité élémentaire de géométrie à quatre dimensions*, which was known in cubist circles.  

Though other authors wrote about themes dealing with the distortion or reordering of time and space, H. G. Wells's novels of the 1890's were by far the most popular and influential. Wells's *The Time Machine*, written in 1895 specifically noted time as the fourth dimension. In this novel, the changes in a particular place are followed through time. In the novel, Wells first referred to the four dimensions as Length, Breadth, Thickness and Duration and then emphasized: "There are really four dimensions, three which we call the three planes of Space, and a fourth, Time."  

Published originally in England, Well's books were published simultaneously in the United States and all of his major works, save for "The Plattner Story," were
translated into French early in the twentieth century. His writings were extremely popular in France. Gaston de Pawlowski was influenced by Wells' writing and published a story called *Voyage au pays de la quatrième dimension* in 1912. Pawlowski's work later influenced Duchamp directly and appears to have had an influence on Gleizes and Metzinger's *Du Cubisme*. The literature of the day provided the public with fantastic images of what might be. These images slowly worked their way into popular thought and affected the arts in a very different way from the sciences.

**PHILOSOPHY**

The influences for the revolution which occurred first in art and then in architecture were not limited to the discussions in mathematics and the physical sciences, and the fantastic images of literature, but came out of philosophy as well. The explorations into the relationship between space and time in philosophy first appeared in the work of Henri Bergson, who was also the most influential philosopher to suggest a changed relationship between space and time.

In 1889, in his *Time and Free Will*, Bergson stated that "the connecting link between these two terms, space and duration, is simultaneity, which might be defined as the intersection between time and space." Bergson said that his first efforts were directed at defining the notion of time, which he felt was currently incomplete.

Bergson's reason for connecting space and time came out of a desire to explain motion. First, time as we know it, can only be measured spatially. We note the passing of time either by the movement of an object (even one as regulated as a watch hand) or by the distance light has traveled. Our perception of each instant is of the location of the objects observed or, in Bergson's words, a sensation. "Space is what enables us to distinguish a number of identical and simultaneous sensations from one another." We perceive motion by stringing a number of these sensations one after the other. What
allows us to perceive a series of sensations as motion is duration, which allows us to make the connection between one sensation and the next.

References to Bergson's philosophy appeared in one of Umberto Boccioni's Futurist manifestos where he recognized Bergson's argument for the indivisibility of time. Boccioni quoted Bergson in his manifesto of "The Plastic Foundations of Futurist Sculpture and Painting" (1913):

"Any division of matter into autonomous bodies with absolutely defined contours is an artificial division.... Any movement, viewed as a transition from one state of rest to another, is absolutely indivisible."\(^{28}\)

While Bergson's philosophy appears to have fit into the arguments of the Futurists, it was not unknown to the Cubists, who were at least made aware of his work by Paul Le Becq in an article on Einstein's theory which appeared in *L'Esprit Nouveau*.\(^{29}\) Though Einstein would later ask God to forgive Bergson for the errors he had made, given Einstein's new theory, Bergson recognized the magnitude of Einstein's work when, upon hearing a lecture about the theory he responded by saying, "I see in this work not only a new physics, but also, in certain respects, a new way of thinking."\(^{30}\)

**SCIENCE**

This "new way of thinking" came about specifically out of Einstein's research. Years later, in a Princeton lecture, Einstein attempted to explain what relativity had meant:

"In pre-relativity physics space and time were separate entities. Specifications of time were independent of the choice of the space of reference.... One spoke of points of space, as of instants of time, as if they were absolute
realities.... Upon giving up the hypothesis of the absolute character of time, particularly that of simultaneity, the four-dimensionality of the time-space concept was immediately recognized. It is neither the point in space, nor the instant in time, at which something happens that has physical reality, but only the event itself.\textsuperscript{31}

The result of this theory was a reality which "entails, not by design but by necessity, a radical reconceptualisation of space and time, henceforth visualised mathematically as a single structure called spacetime."\textsuperscript{32} In his lecture of 1908 (after Einstein's publication), Minkowski echoed:

\begin{quote}
"Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."\textsuperscript{33}
\end{quote}

Though any attempt to simplify Einstein's theory of relativity invariably leads to distortions of his ideas, we may try to explain his relation of space and time as follows: Light travels at a constant speed and our perception of \textit{when} events occur is intimately tied to when we receive the light waves which record the event. If we were to travel at the speed of light, we would be traveling alongside the light waves which recorded the event of our leaving. Because we are assumed to be traveling at the speed of light and that speed does not vary, it would appear that time had stopped because we would be traveling at exactly the same rate as that event. (We can imagine a highway where all cars are traveling at exactly the same speed. If we are in one of those cars, we will be able to tell nothing of what has come before us or what will come later because we appear fixed in time relative to the other cars on the roadway. If instead, we are observing the highway from a stationary point on the side of the road, we will be able to observe time pass as the cars move past us.) The Special Theory of Relativity of 1905 was simply stated by Coveney in \textbf{The Arrow of Time}:
"From the 'common-sense' point of view, the most remarkable properties of special relativity arise from the relativisation of time. The very concept of simultaneity -- events taking place at the same moment -- depends on the relative speed of an observer and is not, as Newton would have it, an absolute concept."34

Later expanded into a General Theory of Relativity in 1916, the latter theory was confirmed in 1919 by Arthur Eddington by measurements made during a total solar eclipse. Only after the validation of his theory did Einstein's work become a part of popular knowledge. The statement of the relativity of space and time was crucial to our rethinking of the subjects of space and time, but another scientific discovery, in which Einstein also played a role, was also crucial to the completion of the revolution of modern physics.

In the same year as the publication of special theory of relativity, Einstein published a paper on the photoelectric effect. This theory suggested that the energy of light was not infinitely variable but came in specific amounts, which he called "quanta." This was the first suggestion that light might be a particle instead of a wave. By 1916, the photoelectric effect had been confirmed, but the full extent of this implication only came in 1924 when Louis de Broglie recognized the relationship between the particle and the wave and proposed that "just as light waves can behave like particles, so too can particles behave like waves."35 In his theory, the larger the mass or the faster the speed, the shorter would be the de Broglie wavelength. His theory, just as Einstein's, only had direct implications when the extremes of speed or mass were reached.

In 1926 and 1927, two scientists working independently in different countries reached very similar and profound conclusions about this wave-particle theory. In Germany, Werner Heisenberg developed the Heisenberg Uncertainty Principle which dealt more specifically with the wave-particle duality. Heisenberg posited that the more
we can know about the location of it as a particle the less we can know about its momentum, and the more clearly we determine the velocity of the wave, the less able we are to make any judgment about the location of it as a particle. We can make the analogy, though far from its original intent of describing the behavior of light, of our ability to judge anything about an object traveling at high speed other than the velocity of the object and, conversely, when an object is stationary relative to our position, the more we can tell about the object and the less we can tell about its speed.

The basic dichotomy recognized here is the meat of the debate happening in art and photography during the end of the nineteenth century and beginning of the twentieth. As we shall see, two major camps developed in art which tried to represent the two extremes. Cubist art attempted to represent the object by presenting many stationary viewpoints simultaneously (representing the object), while the Futurists (in particular the dynamists) attempted to represent the motion of the object by showing its distortion through time. How these two theories are related will be discussed in the section on art, but we may note here that both Cubism and Futurism preceded Heisenberg's statement of the Uncertainty Principle in 1927.

Preceding Heisenberg's Uncertainty Principle by a year, the Austrian Erwin Schrödinger came to very similar conclusions with a different argument. Schrödinger sought to develop de Broglie's wave-particle theory. With a slight addition to the theory by Max Born, a theory emerged which suggested that every particle has a certain wavefunction and that its probability of being found as a particle or wave was dependent on its mass and speed. (It is related to its de Broglie wavelength.) The result of this theory was that any object behaves like a wave until it is seen and, therefore, the observer becomes crucial to the event. Because the theory is intimately linked to probability, causality and determinism were called into question: how can we say that A causes B when there is only a certain probability of A appearing as such or of B appearing as such.
PHOTOGRAPHY

Though the revolution in the physical sciences eventually caused a major rethinking of the way in which we perceive the world, another invention, which came partly out of science and partly out of art, photography, did more to change our perceptions of the world in those early years than did the papers and proofs of science. Roland Barthes, in Camera Lucida, described the effect of photography on our perceptions of time and History:

"Earlier societies managed so that memory, the substitute for life, was eternal and that at least the thing which spoke Death should itself be immortal: This was the monument. But by making the (mortal) Photograph into the general and somehow natural witness of 'what has been,' modern society has renounced the Monument. A paradox: the same century invented History and Photography. But history is a memory fabricated according to positive formulas, a pure intellectual discourse which abolishes mythic Time; and the Photograph is a certain but fugitive testimony; so that everything, today, prepares our race for this impotence: to be no longer able to conceive duration, effectively or symbolically: the age of the Photograph is also the age of revolutions, contestations, assassinations, explosions, in short, of impatience, of everything which denies ripening."36

Barthes later added that in photographs, there is "always a defeat of Time: that is dead and that is going to die."37 His reference to "duration" suggested a reference to Henri Bergson's philosophy discussed earlier.

Beyond questioning the aspect of time we call history, photography granted artists and scientists a way of evaluating our perceptions of objectivity and subjectivity. Leonard Shlain wrote:
"The images provided by the camera, however, also included distortions that were routinely filtered out by the brain.... Since a photograph contains precise information about the visual relationship of points to a whole, which is the basis for the science of perspective, the camera allowed artists for the first time to compare their own observations about nature against an objective standard."38

The camera had no ability to distinguish between subject matter and background and, therefore, showed everything as sharply as the technology allows. It gave us a more accurate representation of space and allowed us to evaluate our perceptions of space and time relative to it.

Along with this idea, and more importantly, the photograph allowed photographers and artists to stop time so that it might be recorded and evaluated more accurately. Originally, the accuracy was assumed to go only as far as we were able to perceive without the photograph. "In the wink of the eye" light can be traced onto the film capturing "the wonders of the deep, the fall, not of the avalanche, but of the apple, the most fleeting smile of the babe... Further than this the powers of photography can never go; they are already more nimble than we need."39 In the years that followed, photography did go beyond this level and allowed viewers to see parts of nature which had never been seen before.

At approximately the same time, Oliver Wendell Holmes, the inventor of the stereoscope, published an essay on the potential of its ability to change the way we view objects. This article, which ran in the Atlantic Monthly in 1859, was not referenced by any of the later artists or photographers, but having appeared in a laypersons' magazine in the United States almost a half century before the debates about the object and multiple viewpoints, we may assume that the effects of the stereoscope may have begun to
undermine the necessity of the object and the ability of multiple viewpoints to represent the object. (19)

Holmes description of the stereoscope established the necessity of at least two viewpoints in understanding an object:

"We see something with the second eye, which we did not see with the first; in other words, the two eyes see different pictures of the same thing, for the obvious reason that they look from points two or three inches apart. By means of these two different views of an object, the mind as it were, feels round it and gets an idea of its solidity. We clasp an object with our eyes, as with our arms, or with our hands, or with our thumb and finger, and then we know it to be something more than a surface...

Though, as we have seen, the two eyes look on two different pictures, we perceive but one picture. The two have run together and become blended in a third, which shows us everything we see in each."40

Holmes imagined the possibility of a color stereoscope and its ability to represent the object or space completely:

"Form is henceforth divorced from matter. In fact, matter as a visible object is of no great use any longer, except as the mould on which form is shaped. Give us a few negatives of a thing worth seeing, taken from different points of view, and that is all we want of it. Pull it down of burn it up, if you please. We must, perhaps, sacrifice some luxury in the loss of color; but form and light and shade are the great things, and even color can be added, and perhaps by and by may be got direct from Nature."41 [My italics.]
Figure 19 -- Stereographic image of the Crystal Palace, circa 1860.
(From *The World of Stereographs* by William C. Darrah, page 103.)
The idea that the object, if given two viewpoints, could be represented and was no longer necessary seems to be almost an exact parallel to the Cubist thought which followed decades later. In addition, Holmes also recognized that it was not the independent views which represented the object, but rather that "the two have run together and become blended in a third, which shows us everything we see in each."

Though it is difficult to determine direct connections between the stereoscope and later changes in art, the popularity of the new invention soon spread from the United States to Europe. And, in 1909, a treatise on the stereoscope indicated that at that time, "Almost every child knows what a stereoscopic photograph is in our hands..." Umbro Apollonio, in his introduction to *Futurist Manifestos*, did draw a connection between the stereoscope and later innovations in art. In particular, we know that Marcel Duchamp was known to have been intrigued by the possibilities of the stereoscope, which he pursued throughout his life. With the help of his friend, Man Ray, Duchamp attempted to uncover the fourth dimension by creating a stereoscopic film of a three dimensional object moving through time:

"Apparently, Duchamp reasoned that if a two-dimensional pattern rotating could generate a three-dimensional virtual image for one eye, stereoscopy's orientation to two eyes should allow a three-dimensional pattern to generate a virtual image of four dimensions."

The ability to stop time led to the ability to dissect time as a series of instances, much in the way that philosophers had proposed was the way in which we view movement. The physiologist, Étienne Jules Marey, who had been recording the graphic image of movement as early as 1860, was the first to try to capture the image of movement in photography. His studies of the flight of birds and other animal movements created quite striking images and sculptures. (20,21) "Chronophotography," as Marey
Figure 20 -- Chronophotographic image of a bird in flight, 1886, by E. J. Marey.
(From E. J. Marey. 1830/1904: *La Photographie du Mouvement*, page 29.)
Figure 21 -- Sculpture of a bird in flight, based on the work of E. J. Marey, 1887. (From E. J. Marey. 1830/1904: *La Photographie du Mouvement*, page 39.)
called it, was specifically reacted against by the Futurist Dynamists. Eadweard Muybridge followed Marey’s idea of using photography to dissect the movement of animals and humans as a series of slices through time. His work began as an analysis of animal motion but, through his inventions for recording these rapid images, his work was instrumental to the invention of cinematography. The impact of this work can be seen directly in the art of the early twentieth century, but we can imagine that these images had made it into popular intellectual circles within the fifteen years following their creation.

The opposite side of photography’s ability to capture the object in a series of slices through its motion was its ability to capture the flow of the motion instead. This was carried out by the Photodynamists of the Futurist movement in an attempt to represent the movement over the representation of the object itself.

"Photodynamism, then, analyses and synthesizes movement at will, and to great effect. This is because it does not have to resort to disintegration for observation, but possesses the power to record the continuity of an action in space, to trace in a face, for instance, not only the expression of passing states of mind, as photography and cinematography have never been able to, but also the immediate shifting of volumes that results in the immediate transformation of expression."46 (23)

Bragaglia’s understanding of an object’s movement in space was uncannily similar to Heisenberg’s Uncertainty Principle, which did not appear until sixteen years later:

"The greater the speed of an action, the less intense and broad will be its trace when registered with Photodynamism. It follows that the slower it moves, the less it will be dematerialized and distorted. The more the image is distorted, the less real it will be.... For Photodynamism, it is desirable and correct to
Figure 22 -- Photos of human movement, by Eadweard Muybridge. (From Eadweard Muybridge, by Kevin MacDonnell, page 115.)
Figure 23 -- *Young Man Rocking*, 1911, by Anton Guilio Bragaglia. (From *Futurist Manifestos*, edited by Umbro Apollonio, page 78.)
record the images in a distorted state, since images themselves are inevitably transformed in movement.

The distinction between space (the object) and time (the motion) is drawn as precisely as it was in philosophy or science:

"We despise the precise, mechanical, glacial reproduction of reality and take the utmost care to avoid it. For us this is a harmful and negative element, whereas for cinematography and chronophotography, it is the very essence. They in their turn overlook the trajectory, which for us is the essential value."

What we see in photography, and what we will see in art, is a separation where one group attempts to evaluate the object in the absence of time, and the other group attempts to analyze motion to the detriment of the object.

ART

This division in art was at its greatest in the years around 1910 to 1914, and had as its influence both work taking place within its own discipline and intellectual influences from other disciplines. Particular attention to the issue of time and space in art has been given in several books. For a more detailed analysis of this discussion, one may turn to Linda Dalrymple Henderson’s The Fourth Dimension and Non-Euclidean Geometry in Modern Art, or a more popular version may be found in Leonard Shlain’s just-published Art & Physics: Parallel Visions in Space, Time and Light. A much briefer discussion of the influences will be given here as we attempt to discover what influences affected the discussion of time and space in art, and then in what way this debate affected the changes in modern architecture.

Prior to the explosion of the Cubist and Futurist movements in the second decade of the twentieth century, at least three artists appear to be manipulating the representation
of space, time, or both. The earliest appearance of an altered perspective in art is seen in the work of Édouard Manet.

Leonard Shlain placed great emphasis on the visual distortions seen in Manet's painting. He credited Manet with being the first to curve the distant horizon line -- thus for the first time representing the fact that we know the horizon line to be curved even though we do not see it as such. Attention was drawn specifically to Manet's *Music in the Tuileries* (1862). Shlain pointed out the fact that there were no perpendiculrals in the entire painting. Even though the actual trees in the Tuileries have grown very straight, Manet had intentionally painted them to appear curved. Not even the standing guests were depicted as true verticals. The lack of straight lines must be seen as an intentional act, however we have no evidence for the intention behind the act. It is an interesting correlation that it was during this time that Riemann first lectured on his theory of a non-Euclidean, curved space (1854) and then published his lecture (1867). In 1859, Manet destroyed all of his paintings and said, "From now on I will be of our times and work with what I see." From the distortion of the horizon line in his later work, *Boats* (1873), we must assume that what he was "seeing" was seen with rather enlightened eyes.

In a different vein of exploration in art, we find time studies appearing in painting during the 1890's and early part of the 1900's. The first to explore this idea of changing time was Claude Monet. During the 1890's, Monet did repeated studies of haystacks and painted the Rouen Cathedral from the same vantage point over forty times and in order to represent the cathedral through time. "Viewing these paintings when they are placed in sequence creates a cathedral that begins to exist in time, as well as in the three dimensions of space."

The last of the painters we will look at before turning to Cubism and Futurism is Paul Cézanne, a known influence on the early Cubist work of Pablo Picasso. Cézanne
Figure 24—*Music in the Tuileries*, 1862, by Edouard Manet.
(From *Manet*, by Françoise Cachin, page 42.)
Figure 25 -- Photo of the Tuilleries gardens, Paris, France.  
(From *Jardins de Paris*, by Jean-Jacques Lévêque, page 28.)
Figure 26 -- The Rouen Cathedral series, 1892, by Claude Monet. (Pissarro, page 95.)
eschewed the single perspective of traditional painting and began to add multiple viewpoints to his paintings. This can be seen as early as 1883 - 1887 in his *Still Life.* (27, 28) In this painting, one notices immediately the inconsistency with which the two vases are represented. Though resting on the same plane, one sees that they are painted from two different perspectives by the differences in the top openings of the vases.

This play of simultaneous perspectives was also noted in Cézanne's studies of Mont Sainte-Victoire, which he painted repeatedly. Unlike Monet's paintings of the Rouen cathedral, which obviously existed at some point *in time,* Cézanne's paintings did away with a specific light source and thus removed the mountain from a place in time. Instead, Cézanne began to incorporate time in his paintings by providing different perspective points within the painting: time is implied as the artist moves from one vantage point to the next. His distortions of the visual world earned him the distinction of being "the Riemann of modern painting," according to Salomon Bochner. Kern describes his efforts to combine multiple viewpoints:

"He sought to reconcile the properties of volumes in three-dimensional space with the two-dimensionality of the picture plane, and his paintings vibrate from the tension. He also wanted to fuse perceptions and conceptions -- the way we see things from a single point of view and the way we know them to be from a composite of several views. Experience tells us that the opening of a vase is circular, but when viewed from the side we see it as an ellipse. Cézanne combines the two perceptions visually with multiple perspectives."52

In these two artists we see the beginnings of the same type of dichotomy about space and time arising as we did in photography. Monet tried to represent the importance of time by depicting the object changing *over* time in a series of views of the object at different times while Cézanne tried to show the significance of the object by representing
Figure 27 -- *Still Life with Fruit Basket*, 1888-90, by Paul Cézanne.
(From *Art & Physics*, by Leonard Shlain, page 116.)
Figure 28 -- Analysis of Cézanne's *Still Life*.
(From Erle Loran, *Cézanne's Composition*, plate 14, copied from Shlain, page 117.)
the different views of it *simultaneously*. This dichotomy reached its height with the invention of Cubism and Futurism.

**CUBISM**

In 1907, the experiments of Paul Cézanne found new life in the work of Pablo Picasso. Picasso's seminal *Les Demoiselles d'Avignon* (29) created a new style of painting, which became known as Cubism. He claimed his early cubist works to be influenced by the still lifes of Cézanne and the "rationality" of African tribal art. The influence of the multiple viewpoints in Cézanne's work can be seen in Picasso's first cubist work, both in the still life in front and the variety of viewpoints from which the body parts are presented.

Beyond the influences of Cézanne and tribal art, Picasso was greatly influenced by his professional relationship with Georges Braque, to whom he was introduced in 1907, just before his work, *Les Demoiselles d'Avignon*. Shortly after Picasso had finished the painting, Braques began experimenting with similar ideas, thus creating a dialogue for experimentation.

Other artists were influenced by the works of Braque and Picasso between 1908 and 1911, when the first public exhibition of cubist works was held in Room 41 of the Salon des Indépendents. Though many of the artists influenced -- including Juan Gris, Fernand Léger, Albert Gleizes, and Jean Metzinger -- displayed their work, Picasso's and Braque's works were noticeably absent. Following the exhibit, Guillaume Apollinaire, the poet who had brought the two together, lectured on the cubist works. It was in his lecture that the term 'fourth dimension' appeared. While Picasso may have gained his original inspiration from African tribal art and the painting of Cézanne, those influences were not enough for the younger adherents to cubism. As Henderson pointed out, those artists sought justification from other disciplines:
Figure 29 -- *Les Demoiselles d'Avignon*, 1907, by Pablo Picasso.
(From Henderson, *The Fourth Dimension*..., plate 12)
"As for their depiction of space, the Cubist painters saw the existence of a fourth dimension as justifying their rejection of the three-dimensional Renaissance perspective. Doubt about the validity of perspective was widespread by the end of the nineteenth century, following Cézanne's pictorial reminder that we see not with a single, unmoving eye (as perspective requires), but with two active eyes set within a head that also shifts."55

Henderson also noted that:

"By November 1911 when Apollinaire first spoke publicly of the cubist painters' preoccupation with 'new measures of space which, in the language of the modern studios, are designated by the term fourth dimension' he could depend on this term's being at least recognized, if not understood completely, by the uninitiated."56

The 1912 book, *Du Cubisme*, Albert Gleizes and Jean Metzinger sought to explain cubist painting and, in so doing, explain the intellectual sources for cubism. Little mention is made of the events happening in the physical sciences, even though as we have noted, Einstein had published his Special Theory of Relativity in 1905 and Minkowski had defined "space-time continuum" in 1908. In fact, there was no mention of "space-time" in the literature of the day and "fourth dimension" did not appear in *Du Cubisme*.57 The book did, however, recognize the correlation between the visual attempts of the cubists and the non-Euclidean space proposed by Riemann during the mid-nineteenth century:

"If we wished to tie the painters' space to a particular geometry, we should have to refer it to the non-Euclidean scholars; we should have to study, at some length, certain of Riemann's [sic] theorems."58
Picasso's own knowledge of the philosophical discussions about space and time prior to his work in 1907 may have come from two sources. Picasso was an acquaintance of an actuary, Maurice Princet, who was known to be interested in the issues of higher mathematics. Princet brought these theories to a discussion group of artists and may have discussed such theories with Picasso upon seeing similarities in his work. Christopher Gray noted that "there is every reason to believe that he may well have contributed to the interest of the Cubists in the newer phases of mathematics through the general discussions on art in which he joined."59 While the degree of Princet's influence is unclear, Henderson seemed certain that the effect of Princet would only have been to strengthen the existing theories of the artists rather than to create them:

"Cubism had been born into an era full of questioning about the structure of our world and the essence of reality. In light of the rise of the new geometries and their great popularity, it is clear that many people in the early twentieth century accepted the possibility of a fourth dimension of space beyond immediate perception. Thus, if someone familiar with n-dimensional geometry, such as Maurice Princet... had pointed out a visual similarity between Picasso's latest painting and a geometrical diagram such as Jouffret's, it would have seemed to confirm the direction Cubism had taken. This demonstration would have reinforced the feeling among some artists that Cubism was indeed right, that they were on the path to a higher reality."60 [My italics.]

In Cubist Aesthetic Theories, Christopher Gray noted the "startling similarity" with which the Cubists seemed to echo the mathematical and philosophical arguments presented by Apollinaire.61 Through the writing of Gleizes and Metzinger, there was little question but what the cubists were more significantly influenced by the writings of
Bergson over those of Einstein and Minkowski. The distinctive terminology used by the different authors leaves a clear imprint on the cubist texts.

The crisis of representation for the cubist artists was one of "portraying things in their entirety, that is, by giving them on the same canvas, as many of the aspects under which they may be seen, as the artist may choose to give." Metzinger later stated that seeing "several successive appearances... fused into a single image" will "reconstitute it in time." The use of the word "time," (in the French, durée) indicates some knowledge of Bergson's philosophy, in which he constantly refers to "duration" whereas, Einstein and Minkowski both refer to temps.

Though the world was changing rapidly in their presence, Picasso and Braque seemed to have taken little interest in the academic events of the day. It appears that only the advances of the Wright brothers were of interest to the two:

"They were captivated by newspaper reports of Orville and Wilbur Wright's conquest of the air. Coinciding with the years of Cubism's development were astounding breakthroughs in many creative and intellectual fields -- from discoveries by Einstein and Freud to Arnold Schoenberg's atonal music, to name only a few - but there is no evidence of Picasso's or Braque's interest in contemporary accomplishments in philosophy, mathematics, or science, with the exception of aviation..."

The first clear indication that the cubists were aware of the advances in the physical sciences by Einstein did not come until the first year of publication for L'Esprit Nouveau, in 1920. In that year, the article "A propos des théories D'Einstein" appeared. In this article, Bergson and Poincaré were specifically mentioned as was the problem of space and time. Readers were told specifically that:

"... new mathematical procedures dictate that a notion of space and a notion of time have, in
Figure 30 — *Man with Violin*, 1911-12, by Pablo Picasso. (From Henderson, plate 17.)
effect, disappeared. It is for this reason that we can express that time has a dimension even though the expression remains outside mathematical symbols."67 [My italics.]

This article appeared shortly after Eddington's proof of the relativity theory and clearly conveyed the revolutionary quality of Einstein's discovery. A "new universal mechanism" was the result of our new understanding of movement, but more importantly, Le Becq stated that:

"The overturning by Einstein of accepted theory on a universal law of mechanics cannot fail to have considerable repercussions in science and philosophical thought."

Interestingly, Le Becq did not mention any possible impact on the fields of art and architecture by this revolutionary theory.

Cubist theory was also effected by other movements in art, most notably the concurrent development of Futurism in Italy. The issue of simultaneity in Cubist art did not arise until after their exposure to Futurism which occurred at a Paris exhibit of Futurist works in 1912.68 While the primary concern of Cubist painting was to represent the object by presenting a variety of views of the object simultaneously, the futurists concentrated instead on representing the continuous motion of the object through time.

FUTURISM

While science had no direct verifiable influence on the origins of Cubism, it figured largely in the statements and expectations of the Italian Futurist movement. From the very beginning, the originators of this movement acknowledged the role of science. The founder of Futurism, F. T. Marinetti, in his 8th point in his "The Founding and Manifesto of Futurism" (1909) was emphatic:

"8. We stand on the promontory of the centuries! ... Why should we look back, when
what we want is to break down the mysterious
doors of the Impossible? *Time and Space died
yesterday*. We already line in the absolute,
because we have created eternal, omnipresent
speed."\(^{69}\) [My italics.]

The reference to speed must surely imply the recent inventions of the age -- the
automobile and telephone, among others\(^{70}\) -- but the specific reference to "Time and
Space" would suggest a familiarity with the changes happening in science.

This transformation caused by science was reiterated in the writings of the
Futurist painters Umberto Boccioni, Carlo Carrà, Luigi Russolo, Giacomo Balla, and
Gino Severini in their 1910 "Manifesto of the Futurist Painters:"

"Support and glory in our day-to-day world, a
world which is going to be continually and
splendidly transformed by victorious Science."\(^{71}\)

Though there may still be some doubt as to whether "Science" here represents anything
other than the inventions of recent years, we gain a more telling view in their "Futurist
Painting: Technical Manifesto" also written in 1910:

"Space no longer exists: the street pavement,
soaked by rain beneath the glare of electric
lamps, becomes immensely deep and gapes to
the very centre of the earth. Thousands of miles
divide us from the sun; yet the house in front of
us fits into the solar disk."\(^{72}\)

The statement that "Space no longer exists" must be a result of the arguments made in the
academic circles regarding space rather than any association to the inventions of speed.
One can find very little correlation between these inventions of speed and
communication and the leap in understanding necessary to reevaluate our perception of
space to account for the fact that how we see the sun, relative to our position in space, is
much different than the fact of the sun, which we understand to be immensely larger than
anything we may witness here on earth.
This was made even clearer in Boccioni's "The Plastic Foundations of Futurist Sculpture and Painting," where he called for the overthrow of the existing understanding:

"Our constructive idealism has taken its laws from the new certainties given us by science. It consists of pure plastic elements, born of an ultrasensitivity which has come as a result of the new conditions of life created by scientific discoveries.

*Our aim is to destroy four centuries of Italian tradition.*"\(^73\) [My italics.]

In a later manifesto, "Futurist Painting and Sculpture," it was clear that it was the overthrow of the existing perspective tradition which was sought:

"commonly held notions on perspective constitute a definite error in terms of true painting."\(^74\)

Futurism was not limited to influences from science. The stereoscope, which we have noted was very popular in France, affected both the Futurists and Cubists as Umbro Apollonio discussed in his introduction to **Futurist Manifestos:***

"The Futurists, like the Cubists, were influenced by stereometry; the cubists, however (at least in the beginning), took advantage of polycocular vision, so that the object is in a static situation, involved in relations with other objects and the environment, whereas the Futurists, for the most part, superimposed one object on another, or the environment on the object, breaking it up into a dynamic state which is the reflection of the surrounding movement. The transparency of the bodies in Cubist painting is such as to show the interweaving of different points of vision in a single object whose profiled fragments reappear displaced with respect to their original positions. The Futurists, on the other hand, present the object in all its solidity, almost indeed simulating its projection into the space..."
which contains and conditions it. For the Cubists, the composition is always based on a single axis and portrayed in a regular pattern. The Futurists, on the other hand, used several axes, which cross each other and introduce a combinatory play of multiple intersections.\(^7\)

These two movements were able to use common inspirations to surprisingly different results, but they were also able to learn from each other.

In particular, the work of the Italian Futurists was further affected by their exposure to the Cubist works exhibited in Paris in 1911. According to Apollonio, Boccioni wrote a letter from Paris after the show stating that "he had already intuitively anticipated most of the innovations he found in the modern paintings so much admired there.... Nothing of the complex aspirations of the most advanced modern painting had escaped his notice (and these are his own words)."\(^7\)

A year after the Cubist exhibit which Boccioni saw in Paris in 1911, the Futurist painters exhibited their work in Paris. Though the Parisians compared the Futurist work to that of the Cubists and Cézanne,\(^7\) Boccioni differentiated between the "dead" works of Picasso and his own works:

"In fact Picasso copies the object in its formal complexity, taking it to pieces and numbering its various aspects. In this way he prevents himself from experiencing it in action. And he would not be able to do so, because the way he proceeds, the enumeration which I mentioned, freezes the life of the object (motion), detaches the constituent parts, and distributes them about the picture in accordance with an incidental harmony inherent in the object.

However, the analysis of the object is always at the expense of the object itself -- it kills it....

This is a scientific analysis which studies life by looking at a corpse, dissecting the muscles, arteries and veins, in order to study their functions and discover the laws of creation. But
art is creation itself, not an accumulation of knowledge."³⁸

Nevertheless, Boccioni appeared to have had an interest, or at least contact, with the Cubist material from France. In "Futurist Dynamism and French Painting" (1913), two years after Boccioni’s excursion to see the Cubist works, and a year after the Futurist exhibit in France, Boccioni referenced a French article by Léger published only two months before the publication of his own essay.³⁹ This indicates that Boccioni must have had continued contact with the French painters either through direct contact or through their literature.

While the Futurists may have been indirectly affected by philosophy and the sciences through their contact with the Cubists, we can be sure that they were directly affected by the problem of time which Bergson presented. In "The Plastic Foundations of Futurist Sculpture and Painting," Boccioni found a strong correlation between the Futurist works and the philosophy of Bergson:

"Any dividing up of an object's motion is an arbitrary action, and equally arbitrary is the subdivision of matter. Henri Bergson said: 'Any division of matter into autonomous bodies with absolutely defined contours is an artificial division', and elsewhere: 'Any movement, viewed as a transition from one state of rest to another, is absolutely indivisible."³⁶

It is, however, surprising that in the Futurist publication, Lacerba, there was no direct reference to any of the scientific discoveries being made.³¹

Unlike the Cubists who were interested in "portraying things in their entirety," the Futurist were interested in representing "the dynamic sensation itself."³² This representation of the dynamic necessarily meant that the accurate representation of the static object was sacrificed. In the early statements of this idea, the static object was
replaced by one which more accurately represented their impression of the object in motion:

"A profile is never motionless before our eyes, but it constantly appears and disappears. On account of the persistency of an image upon the retina, moving objects constantly multiply themselves; their form changes like rapid vibrations, in their mad career. Thus a running horse has not four legs, but twenty, and their movements are triangular." 83

This attitude of the early Futurist painters was taken seriously, as one can see in Giacomo Balla's *Leash in Motion* of 1912. (31) This early statement was also very reminiscent of the chronophotography of Marey, but as Henderson noted, the Futurists' connection with Bergson's philosophy made them search for a greater continuity of motion which was fulfilled in the Dynamist sub-movement:

"the Bergsonian orientation of the Futurist Boccioni led him to reject all analyses of motion in the manner of chronophotography, Boccioni was seeking a fluid continuity..." 84

As dynamism developed, the multiplicity of the object was replaced by the fluid dynamic of the object. This is seen first in the Futurist Photodynamist manifesto of Anton Giulio Bragaglia in 1911 and later in Boccioni's "Plastic Dynamism" of 1913 as he first defines and then explains this change from his multiplicity of 1910:

"Plastic dynamism is the simultaneous action of the motion characteristic of an object (its absolute motion), mixed with the transformation which the object undergoes in relation to its mobile and immobile environment (its relative motion)....

It seems clear to me that this succession [an infinite succession of events] is not to be found in the repetition of legs, arms and faces, as many people idiotically believed, but is
Figure 31 -- *Leash in Motion*, 1912, by Giacomo Balla.
(From *Futurist Manifestos*, edited by Umbro Apollonio, page 79.)
achieved throughout the intuitive search for the one single form which produces continuity in space. This is the key to making an object live in universal terms."85

This "intuitive search" was well-represented in his sculpture of the same name. (32) One can easily read the movement of the human body in this sculpture, though the figure itself is obscured by the representation of motion.

This effort to represent the motion was specifically tied to the current interest in the fourth dimension. Though we see the connections throughout the Futurist literature, Boccioni stated this explicitly in his "Plastic Dynamism" essay: "dynamic form is a species of fourth dimension, both in painting and sculpture."86 It was specifically an effort to represent the new perception of reality:

"No one still believes that an object finishes off where another begins or that there is anything around us -- a bottle, a car, a house, a hotel, a street -- which cannot be cut up and sectionalized by an arabesque of straight curves."87

and to find an expression for their own age:

"With dynamism, then, art climbs to an ideal, superior plane, creating a style and expressing our own age of speed and of simultaneity."88

The Futurist movement was cut short in Italy by the First World War. Because the Futurists had called for revolution, many were anxious to join military ranks in this revolution -- among them Boccioni, Marinetti, Balla, and the Futurist architect, Sant'Elia. Many of them died during the war or returned profoundly changed.89 By that time, however, the Futurist movement had already appeared in most of Europe. Beyond Boccioni's own influence, Banham stated that Futurist influence had been seen in

"Paris (1912, 1913,1914), London (1912-13), Rotterdam and Berlin (both in 1913) while all
Figure 32 -- *Unique Forms of Continuity in Space*, 1913, by Umberto Boccioni.
(From Henderson, *The Fourth Dimension...,* plate 31.)
or part of the exhibition held in Paris in 1912 seems to have been seen in Brussels, Berlin, Hamburg, The Hague, Leipzig, Munich, Vienna, Breslau, Wiesbaden, Zurich and Dresden, and in every case was accompanied by Manifestoes, some of which were available in German, Spanish, and Russian by 1914, as well as the 'original' French and Italian.↵

Both Cubism and Futurism were very influential in defining a new type of space, but as we have seen in the work of Frank Lloyd Wright, Le Corbusier and Theo van Doesburg, the new types of space which were presented to the public did not represent a unified understanding of what this new space was. In both cases, the Renaissance perspective was abandoned for an artistic style which the artists felt would more adequately represent the object or event.
THE INFLUENCES OF ARCHITECTURAL CHANGE

From the discussion of the preceding disciplines, we can see how the ideas of a changed space and time have been appropriated by different fields. The fantastic nature of the ideas of a fourth dimension or of a non-Euclidean geometry fed the imagination of those in other disciplines, as we witnessed in particular in the case of the literature of the day. Though the applications in literature had some foundation in the scientific, mathematics and philosophic theories, they were not bound by the rigid arguments of those disciplines. The general public had some understanding of the phrase "space and time are relative," but the scientific arguments which comprised that argument were much more exact and more difficult to understand.

THE INFLUENCES OF FRANK LLOYD WRIGHT

Frank Lloyd Wright, the earliest of the three architects whose changes in spatial perception we have examined, appears to have had little direct influence from the theories of the time. Giedion suggested that one of the reasons he was able to do more was because "he had less debris to chase away than the Europeans."91 On the other hand, Henderson has noted that there were a large number of popular articles published on both
n-dimensional space and non-Euclidean geometries, which he may have been exposed to through the debates published in the popular media of the day. Regardless of whether or not he read these articles, one can find no direct reference to it in his work.

The first direct influence on his work, and the one most clearly related to his perception of space, were the Froebel gifts, which his mother employed during his early years of education. These gifts, and the philosophy behind their use, were designed to teach one about the Forms of Knowledge, Life and Beauty. An important part of the designs made with each set of blocks was that all designs were to be created symmetrically. As Richard MacCormac noted in his essay, "Form and Philosophy: Froebel’s Kindergarten Training and the Early Work of Frank Lloyd Wright": "In Froebel patterns, symmetry is employed not only to effect balance, but to realize interpenetration." As demonstrated in the patterns of the fifth and sixth gifts (33), the symmetrical arrangement allows one to see larger spatial organizations within the arrangement of the blocks. In a simpler example (34), four square blocks spaced equally apart from each other allow one to see the original four blocks, but in addition, one can imagine an organizing grid within which they are located, a larger square formed by the original squares, and also a smaller square made up of the space between the four inner tips of the original four squares. The implementation of these skills inherently gave Wright a sense of interpenetrating volumes regardless of whether or not he sought them in his work.

In addition to the Froebel gifts, Wright appears to have been affected most deeply by his physical environment and the politics of his country. He did not speak specifically of space in his architecture until after 1928. Wright described the midwestern prairies and suggested how architecture might follow in his essay, "In the Cause of Architecture" written in 1908:
Figure 33 -- Patterns made from the fifth and sixth Froebel gifts.
(From MacCormac, page 105.)
Figure 34 -- An example of the interpenetration of space created from the simple use of symmetry in the Froebel system.
"We of the Middle West are living on the prairie. The prairie has a beauty peculiarly its own and we should recognize and accentuate this natural beauty, its quiet level. Hence, gently sloping roofs, low proportions, quiet sky lines, suppressed heavy-set chimneys and sheltering overhangs, low terraces and out-reaching walls sequestering private gardens."  

Later in the same essay, Wright also recognized the unrest of the period, but did not specifically relate this to changing ideas of space. He argued only that "...the forms must be born out of our changed condition." The closest parallel to a statement about space in this early essay lie in his discussion of the use of perspective in architecture:

"I have great faith that if the thing is rightly put together in true organic sense with proportions actually right the picturesque will take care of itself. No man ever built a building worthy the name of architecture who fashioned it in perspective sketch to his taste and then fudged the plan to suit. Such methods produce mere scene-painting. A perspective may be a proof but it is no nurture."  

We have no other clue from his writing whether or not he was aware of the debates in art regarding the use of perspective.

Through Wright's writings we are lead to the conclusion that his investigations of space were not his primary aim, but instead that spatial expression was only the tool for the representation of his ideas. These ideas, as we have seen, sprang from a desire to represent democracy and the land on which he lived. Nonetheless, other architects of the time found in his work at least a partial solution to their own problems.

Wright was particularly influential among the northern Europeans, where Berlage had first noticed Wright's work during his 1911 visit to the United States. His influence in De Stijl is evident. One can see this in particular by comparing Robert van't Hoff's 

Huis ter Heide (35), built in Utrecht in 1916, with Wright's Emma Martin House and
Robie House. (35) J. J. P. Oud wrote of Wright's influence in his essay for the Wendigen edition in which he stated that Wright "towers so assuredly above the surrounding world." He also paid homage to Wright's contribution to European architecture:

"The shifting of planes, the projecting penthouse-roofs, the repeatedly interrupted and again continued masses, the predominantly horizontal development, all typical of Wright's art appear at the time when the spirit of Wright's works began to influence our part of the world, as characteristic features of a considerable portion of modern architectural products in Europe."100

One notes that those aspects of Wright's work which influenced others were his ideas about a new conception of space and not the larger issues he had sought to address.

This was also true of later historians. In the Wendigen edition, Lewis Mumford referred to him as a "poet of space" who had "absorbed the broken rhythm of the machine, [and felt] the jagged geometry of our new adventures of space."101 Peter Collins later wrote that:

"...whereas the Rationalists, such as Viollet-le-Duc, could conceive only the structure of churches as providing the archetype for a new way of building, Wright took the space; and it is this which distinguishes Wright from the other great architects of his generation (such as Perret) as the first great architect of the twentieth century."102

THE INFLUENCES OF LE CORBUSIER

Le Corbusier's exposure and reaction to issues of space differ from that of Frank Lloyd Wright. Early readings directed his outlook on art and architecture, but later
Figure 35 -- Huis ter Heide, Utrecht, 1916, by Robert van't Hoff.
(From De Stijl, by Hans L. C. Jaffé, page 195.)
exposure to the scientific debates of the day were not applied to his architecture. Paul Venable Turner, in his book The Education of Le Corbusier, has given a great deal of insight into his early years.

One of the books that appears to have been the most influential to his early years (and very influential in his understanding of objects in space) was Henry Provensal's L'art de demain. Because the book is not readily available, we must rely heavily on the information provided about this book by Turner.\textsuperscript{103} Published in 1904, it was a part of the then Charles-Édouard Jeanneret collection sometime before 1907. Provensal's book was important to Le Corbusier's early years because it suggested a coming revelation, a necessary connection between art and science, and a geometric way of viewing the world. According to Turner, the book was important for the

"...suggestion, throughout the book, of imminent discovery, progress, and revelation, the idea that whereas the cultural situation is wretched now, things are about to change, a new harmony is about to be established, and new artistic giants are about to reveal themselves and assume their rightful roles.... Typical of this attitude is the idea that new architectural 'laws,' presently still undiscovered, will soon be revealed.\textsuperscript{104}"

Part of this change would be in the combining of art and science:

"According to Provensal, the new utopian age of science-art is imminent. He predicts a long period of peace, in which the new artist will thus become a great directing figure, 'le chef éminent,' who will oversee the elevation of Man's soul...\textsuperscript{105}"

These attitudes may have effected the way in which Le Corbusier viewed himself as an artist and later architect, but the impetus for the geometrization of the world is found elsewhere in Provensal's text.
Provensal promoted a "cubic" way of looking at the world. This pre-Cubist attitude had nothing to do with the representation of multiple viewpoints, but rather with a purity of geometric expression in nature. Turner quoted Provensal:

"...nature has given architecture invariable forms, as a point of departure, from which it can draw the first elements of its conceptions."\textsuperscript{106}

Because Le Corbusier's early sketches and watch case design of 1902 already showed a predisposition for geometric designs, this passage may have only been further encouragement. (36) One, however, does not find any sign of this geometrization of nature in his earliest architectural work as we have already seen.

We can see the lasting influence that Provensal had on Le Corbusier if we compare one of his quotes with Le Corbusier's later statement about architecture. In 1904, Provensal had written:

"The opposition of shadow and light, of full and empty, the cubic conclusions of its three dimensions, constitute one of the most beautiful plastic dramas of the world."\textsuperscript{107}

Some 16 or so years later,\textsuperscript{108} Le Corbusier echoed:

"Architecture is the masterly, correct and magnificent play of masses brought together in light."\textsuperscript{109}

Le Corbusier's greatest exposure to the scientific and spatial issues of the day came through his partnership with Amadeé Ozenfant, whom he met in 1918. Ozenfant was a painter and very interested in the debates going on in the sciences as well as the art of Cubism. Ozenfant's information about space and time came partially from the lectures of Henri Poincaré\textsuperscript{110} and through the Cubists, though he used it to his own end. He was very interested in the philosophy of Poincaré, who as we have discussed earlier, was most famous for his arguments that one could never prove or disprove Euclidean space.
Figure 36 -- Watch case design, c. 1902, by Charles-Édouard Jeanneret.
(From Le Corbusier: Ideas and Forms, by William J. R. Curtis, page 19.)
Comments made in his later book, *The Foundations of Modern Art*, show that by 1931, Ozenfant was well-versed in these theories. Though this publication is well past the 1918 publication of *Après le Cubisme*, we may assume at least, that his interests in the scientific works were genuine. In the introduction to *The Foundations of Modern Art* he wrote:

"Galileo pointed out that it was not the sun which moved, as the Bible asserted, but the earth: the Galilean universe was still that to which our senses bore witness, an Euclidean universe: but thanks to Gauss, Riemann, Lobatchewsky [sic], the poet-mathematicians Poincaré and Einstein dared envisage a space that our senses could not know, with the result that the common sense of Descartes is proved wrong by their untramelled and lyrical imaginings. At which point our universe becomes a hypothetical one, based on astonishing laws, with geometries of more than three dimensions, which go so far as to assume that, owing to the curvature of space, the rays issuing from the sun curve at the extreme limits of space and return to their point of departure."111

Though he understood the arguments of science, the issues of art and science were always seen as separate realms for him. In Henderson's account of the influence of modern geometries on art she wrote:

"...although the Purists were actively involved in the popularization of Einstein's theories in *L'Esprit Nouveau*, Ozenfant and Le Corbusier made no attempt to adjust their art to reflect Einstein's world view."112

In fact, their movement, which they called Purism, was founded on correcting what they considered to be the problems of Cubism. They felt that the fourth dimension was fully unrealizable in the field of art because we can only experience three dimensions. The
fourth dimension was simply an intellectual construct which could not be viewed by humans and was, therefore, not to be used in art or architecture. According to Cornelis van de Ven, who wrote a history of architecture based on the primacy of space:

"Jeanneret and Ozenfant felt that even in the sciences the concept of the fourth dimension was wholly speculative and out of touch with the 'real world,' since the human senses can only distinguish a space of three dimensions. Consequently they proposed an alternative trend, called Purism, in which all these fallacies would be corrected."[113]

A quote from Après le Cubisme made this point clear:

"Here briefly is why it is absurd to pretend to express other dimensions than those our senses perceive: the third dimension of perceptible space, named depth, was at one moment excommunicated by certain cubists, in favor of a certain fourth dimension which the superficial reading of scientific works had caused to be 'invented.' They forgot that the fourth dimension of the mathematicians is an entirely speculative abstraction, a part of hypothetical geometry, a marvelous play of the intellect, with no material contact with the real world, conceivable but not representable, since the human senses distinguish only three dimensions in space."[114]

Their movement derived its name from the desire for purity of form, something we have seen in the writing of Provensal.

In The Foundations of Modern Art, Ozenfant's discussion of architecture included a desire that it be lyrical and functional. In it, he discussed the new technological advances which had made the new architecture possible, but in his discussion, Ozenfant never mentioned architectural space.[115] What seems clear is that Le Corbusier was exposed to the arguments of space and time, through the Cubists and
Ozenfant, even if he did not follow that intellectual current in Paris on his own. Through Provensal, he was exposed to the possibilities of coming revelations in art and architecture, which he felt himself to be a part of, and he was exposed to Provensal's ideas of the merging of art and science. Yet despite all of these exposures, Le Corbusier chose not to involve himself in the questions of space per se. Le Corbusier's work was about an architecture of the times which would be based on the technology of the day and the primacy of the pure form. The changes in his architectural space differ both in origin and in effect from that of Frank Lloyd Wright.

THE INFLUENCES OF THEO VAN DOESBURG

Of the three architects, Theo van Doesburg was the one to become the most involved in the debates of the day concerning space and time. As we have seen in the axonometric he did for his private house project with Cornelis van Eesteren, van Doesburg specifically tried to represent the issues of space and time. His desire to include the idea of a transformed space and time is made even clearer by his 10th statement in "Towards Plastic Architecture:"

"10. Space and Time. The new architecture takes account not only of space, but also of time as an aspect of architecture. The unity of time and space gives the appearance of architecture a new and completely plastic aspect (four dimensional temporal and spatial plastic aspects)."116

His first exposure to these issues appears to have come from his awareness of the Futurist movement in 1912. Joost Baljeu, in a book on van Doesburg, stated that in 1912, van Doesburg rejected the Futurist movement as being too "superficial."117 During the following years, however, he read the writings of this group (Marinetti and Boccioni) and others (Berlage and Kandinsky) and, thus, must have come into contact with the
arguments of Bergson and the Futurists' urgency of a representation of speed brought about by the recent inventions. He was an admirer of Theosophy, a group associated with spirituality and an adherence to hyperspace philosophy, another nth-dimensional construct.

During 1915, van Doesburg had his first contact with the work of Piet Mondrian, which he admired for its "spiritual and architectural" qualities. His correspondence with Mondrian exposed him to the other issues of the space-time debate through the Cubist movement. In 1917, Mondrian wrote in *De Stijl* that

"The rhythm of relationship of color and dimension (in determinate proportion and equilibrium) permits the absolute to appear within the relativity of time and space."  

With such specific reference to "the relativity of time and space," we must assume that Mondrian was familiar with the work of Einstein, even if only in passing. In 1918, van Doesburg stated in an article that:

"The artist visualizes plastic relationships. The painter visualizes colour, the sculptor form and the architect spatial relationships."

This was the first clear statement that, unlike the other two architects we have discussed, van Doesburg's primary architectural concern was *space*.

Through Robert van't Hoff, around 1918, van Doesburg became familiar with the thought of Berlage (and Wright). Berlage's appreciation of Wright's work was in the built forms. In the *Wendigen* edition, an essay by Berlage described the uniqueness in his work:

"But that leap of the roof, with its tremendous shade effect, through which its protective function (never so prominent as with Wright) found expression, is and remains the find, the
fascinating piquancy of the 'tridimensional', as a pupil of Wright's characterised his work."¹²²

J. J. P. Oud, another architect who became prominent in De Stijl, published articles on Wright's work in *De Stijl* and also wrote an article on his influence in Europe for the *Wendingen* edition. Oud's essay, as we have already noted, concentrated on the spatial aspects of Wright's style more than his stated agenda.

The writings of van Doesburg are littered with references to the specific issue of space and time. In his lecture, "The Will to Style: The reconstruction of life, art and technology," given in 1922, van Doesburg directed the need to apply space and time to work of art because of changes in science:

"As a result of the scientific and technical widening of vision a new and important problem has arisen in painting and sculpture beside the problem of space, and that is the problem of time."¹²³

Van Doesburg's clearest statement about architecture is in his 1924 manifesto, "Towards Plastic Architecture." This essay, as we have seen, was devoted entirely to the spatial and formal aspects of architecture. There was no reference either to social conditions or mechanical innovations. In his case, unlike that of Wright or Le Corbusier, the stated philosophies about architecture were purely in spatial terms.

Having looked at the influences of Wright, Le Corbusier and van Doesburg, we are convinced that they shared few influences in common. Le Corbusier and van Doesburg were both influenced by the art of the time, but they followed paths which we have already seen were contradictory in their goals and the representation of space. Le Corbusier, though not following specifically in the Cubist tradition, was influenced by their work. His spatial conceptions in architecture were in opposition to the Cubists' desire to represent the fourth dimension in their work. Cubist painting, however, was but one influence in Le Corbusier's architecture and, though he recognized a new space
conception, his influences and driving forces in architecture came from sources other than those on the debate of the conception of space.

In the case of Theo van Doesburg, his architecture was almost diametrically opposed to the spatial conceptions of Le Corbusier. Van Doesburg was also influenced by the Cubist tradition through his association with Piet Mondrian, but aligned himself more directly with the Futurist movement, which concerned itself more directly with space and time. Where Le Corbusier's spaces become well-defined volumes contained within an envelope, the space and time influences of van Doesburg led him to an architecture based on the extension of planes in space, a much freer representation of space in architecture.

We have seen the differences in both the space conceptions and early influences of Wright, Le Corbusier and van Doesburg. Based on these differences, we must reevaluate the claims of those, such as Sigfried Giedion, who have seen the change away from the Renaissance perspective as a new stage in architecture. As we have discussed earlier, Giedion's proposed history closely parallels the paradigm shift theories of Thomas Kuhn. Do the work of these three architects support a claim that architecture went through a paradigm shift based on a new conception of space? And what can be said about the architectural histories based on changing conceptions of space?
KUHN'S THEORY OF SCIENTIFIC RESEARCH

Thomas Kuhn's theory of Paradigm Shifts was derived as an explanation of the way in which scientific research occurred. He argued that by looking at the record of scientific research, three basic types of research emerge. The first stage of research is that which takes place prior to the establishment of an operative paradigm. During this early, "pre-paradigmatic" stage, research or experimentation is "characterized by continual competition between a number of distinct views of nature, each partially derived from, and all roughly compatible with, the dictates of scientific observation and method."

Once a paradigm is established, a second type of research, "normal science," occurs. The goal of normal science is to further the understanding and applicability of the reigning paradigm. Kuhn divides "normal science" into three groups which reflect the goals of the researcher. These goals are: 1) to further classify the relevant information; 2) to compare measured results against predicted outcomes based on the paradigm; and, 3) to articulate and classify the paradigm. There are usually few challengers to a paradigm because most members of a generation are brought up under the existing paradigm. Kuhn remarked that "perhaps the most striking feature of the
normal research problems ... is how little they aim to produce major novelties, conceptual or phenomenal."\textsuperscript{126}

The third type of scientific activity occurs when a crisis is reached and it becomes apparent that the scientists do not "know what the world is like."\textsuperscript{127} This period comes about when normal research keeps producing anomalies in experimental results which do not fit with the existing paradigm and a crisis results. A new paradigm results when scientists are able to "switch" their view of the world to a different theory which accounts for the anomaly.

New paradigms are not created \textit{de novo} but come as a reaction to perceived insufficiencies in the operating paradigm. Einstein sought to redefine space and time only when he found that the current definitions failed to explain all observed occurrences. A new paradigm cannot arise without some recognized insufficiency within the existing paradigm of the time. Kuhn was very clear about the tempo of scientific research as well.

\textbf{THE TEMPO OF SCIENTIFIC RESEARCH}

Kuhn's work suggested that there are long periods with relatively little change ("normal science") varying around the existing paradigm, alternating with brief periods of crisis and quick, sometimes violent change (depending on its place in the hierarchy of paradigms) resulting in paradigm shifts. Kuhn's theory recognized that the long periods within a scientific discipline during which only slow, gradual change is made is based on small refinements of the existing paradigm ("normal science"). In the briefer episodes, times of crisis arise which make it difficult to accept the existing paradigm, and a new one is developed.

The actual paradigm shifts are referred to as "non-cumulative developmental episodes in which an older paradigm is replaced in whole or in part by an incompatible
new one."\textsuperscript{128} Because the two theories (the old and new paradigms) are incompatible, the shift in paradigms is a very quick, almost instantaneous occurrence. According to Kuhn, "when the transition is complete, the profession will have changed its views of the field, its methods, and its goals."\textsuperscript{129} He likened a paradigm shift to a change in visual gestalt.

\textbf{THE EVIDENCE OF SCIENTIFIC REVOLUTIONS}

It may not always be easy to identify when exactly "new understandings" in history come into existence. Kuhn noted three different occurrences which parallel paradigm shifts. First, he noted that instances of simultaneous, independent discoveries appear to be the most visible evidence of scientific revolutions. Kuhn referred to several of these instances which range from the discovery of oxygen and the invention of calculus to the discovery of a mechanism for biological evolution and the relativity and quantum revolutions. While these occurrences were prominent indicators of scientific revolutions, Kuhn noted two other signs which also may indicate a paradigm shift.

In Kuhn's discussion of pre-paradigm scientific research, he noted that:

"The preparadigm period, in particular, is regularly marked by frequent and deep debates over legitimate methods, problems, and standards of solution, though these serve rather to define schools rather than to produce agreement."\textsuperscript{130}

This passage points out two important pieces of information. First, that pre-paradigm periods will be evidenced by "frequent and deep debates," but also that prior to the establishment of a paradigm one would expect to see many different schools rather than agreement on one particular view. While he specifically noted these debates taking place prior to the establishment of a paradigm, he later stated that:

"... they [debates] recur regularly just before and during scientific revolutions, the periods
when paradigms are first under attack and then subject to change."\textsuperscript{131}

Kuhn suggested that a third way of determining whether or not a scientific revolution has occurred might be found in the scientific writings of the time. In his introduction he suggested that an index for these revolutions might be found in the primary literature of the time. If paradigm shifts really do fundamentally change the way in which we view science and its history, we should find an immediate shift in the references and footnotes in technical documents.\textsuperscript{132}

**THE SIMILARITY WITH ART AND ARCHITECTURE**

Kuhn's theory of scientific research has been a likely candidate for those looking for a pattern in architectural history as well. Parallels have been drawn between the shift from pre-Einsteinian to Einsteinian physics and the change from pre-modern to modern architecture.\textsuperscript{133} On one level, it is quite easy to see the parallels which can be drawn between scientific and architectural change. A similar understanding of how art forms change through time was noted by Henri Focillon in 1934, twenty-eight years before Kuhn's original publication.

**HENRI FOCILLON AND THE LIFE OF FORMS IN ART**

In *La vie des formes*, reprinted in English as *The Life of Forms in Art*, Focillon stated that:

"The history of forms cannot be indicated by a single ascending line. One style comes to an end; another comes to life. It is only natural that mankind should reevaluate these styles over and over again, and it is in the application to this task that I apprehend the constancy and the identity of the human spirit."\textsuperscript{134}
Focillon presented three states to the life of a style. The first is the experimental state, also known as archaism, in which the "style is seeking to define itself." During this period, "experimentation proceeds with disconcerting speed" and, as Focillon so eloquently put it, "It dreams of monsters that it has not yet turned into men." In describing the archaism of the Gothic: "It multiplies structural experiments, creates types that would normally be considered as stopping points and continues to renew them until, with Chartres, its future has been, as it were, ordained." This state parallels the pre-paradigmatic stage of Kuhn which was "characterized by continual competition between a number of distinct views of nature, each partially derived from, and all roughly compatible with, the dictates of scientific observation and method."

The second state of a style of forms Focillon referred to as the classic state. This state may be likened to the moment of the paradigm shift.

"It is stability, security, following on experimental unrest. It confers, so to speak, a solidity on the unstable aspects of experimentation (because of which it is also, in a way, a renunciation).... But classicism is not the result of a conformist attitude. On the contrary, it has been created out of one final, ultimate experiment, the audacity and vitality of which it has never lost." This "ultimate experiment" would appear to be the equivalent of Kuhn's statement of a new paradigm. At that point, a new explanation of how the world works has been achieved. It was only after further experimentation that a new occurrence arose which caused a rethinking of the paradigm. Temporality of the event was reflected in Focillon's description of classicism as:

"... a brief, perfectly balanced instant of complete possession of forms; not a slow and monotonous application of "rules," but a pure, quick delight, like the αἰμή of the Greeks, so..."
delicate that the pointer of the scale scarcely trembles."138

The equivalent of Kuhn's "normal science" in this theory was the academic state. Focillon described it as "merely a lifeless reflection, a kind of inert image." The academic state was the final state of a style before it was replaced by a newer style. Focillon's description paralleled Kuhn's definition of "normal science" as a time of refining the existing paradigm:

"This is not the place to show how forms pass from the classic state to those experiments in refinement that, as regards architecture at least, have the elegance of structural solutions to what may seem a very bold paradox, and that reach the state of dry purity and of calculated interdependence of the parts so singularly well-expressed in the style known as art rayonnant."139 [My italics]

Though Focillon did not offer an exact parallel to Kuhn's argument, what was important was that historians in other disciplines had also been searching for principles which guide changes within a discipline and that those principles appear to parallel each other in different disciplines. Focillon's observations about changes in artistic form gave increased reason to look for such parallels in architecture. The parallels were easily found between Kuhn's theory and architectural history.

THE TEMPO OF ARCHITECTURAL CHANGE

Similarities in the tempo of change in architecture and science are well documented. The recognition of crises and periods of stasis are evidence not only of the crises and resultant paradigm shifts, but just as importantly they note the periods of stasis between crises which we may recognize as "normal architecture."
The earliest record of observations of such a tempo in architecture is found in an 1849 passage by the engineer Jean-Baptiste Jobard. His comments paralleled Kuhn's observations of 117 years later and provide a key to understanding architectural change.

"Architectural revolutions always follow social revolutions. In the interim periods few changes are to be seen, no matter how long these periods may be. Men insist upon remedying the old forms until a radical upset wiped the slate clean of banal schools and ideas.

"There are great periods in architecture just as there are great geological periods: a new race of plants or animals only appears after the disappearance of the old. In architecture it is the same: the race of the old authorities in architecture had to be superseded -- just as the mastodons were superseded -- in order to make room for new kinds of artists who will not preserve the traditional prejudices of the old schools.

"But, you may say, where shall we find masters clever enough? We should not tell you to seek these people among the old masons whose hands have been so long occupied with stone and mortar that it is safe to presume that their brains also move in an equally restricted orbit. To create what is new, you must have young people"140

Jobard described the tempo as interim periods with few changes separated by periods of revolution. In addition, he saw, as Kuhn later did, that the changes would arise out of the youth of the discipline.141 Most importantly, however, Jobard recognized the close relationship between social and architectural changes.

Kuhn stated over and over in his work that it was almost impossible to determine exactly who was the instigator of any one paradigm shift because, in most cases, several researchers had made simultaneous discoveries. A similar pattern was noted in a quote by Auguste Choisy referenced by Reyner Banham:
"It is the nature of Gothic, as with all discoveries, that we can rarely manage to name the true inventor without dispute; the seeds incubate in obscurity, and suddenly we witness various hatchings that imply only the logic of facts." [My italics.]

Such descriptions of architectural change are found in the writings of architects as well as those by historians. Le Corbusier's call for architectural change, "Architecture or Revolution" in *Towards a New Architecture*, described the changes he felt were necessary in architecture. They are hauntingly reminiscent of the tempo suggested by Kuhn though they are written almost forty years before. In his introduction, Le Corbusier wrote:

"The history of Architecture unfolds itself slowly across the centuries as a modification of structure and ornament ... If we challenge the past, we shall learn that 'styles' no longer exist for us, that a style belonging to our own period has come about; and that there has been a Revolution."  

The tempo which he began to articulate in the introduction, slow change followed by revolution, was made clearer in the last section of his book, "Architecture or Revolution":

"We do not appreciate sufficiently the deep chasm between our own epoch and earlier periods; it is admitted that this age has affected a great transformation, but the really useful thing would be to draw up a parallel table of its activities -- intellectual, social, economic, and industrial -- not only in relation to the preceding period at the beginning of the nineteenth century, but to the history of civilization in general. It would quickly be seen that the tools that man has made for himself, which automatically meet the needs of society, and which till now had undergone only slight modifications in a slow evolution, have been
transformed all at once with an amazing rapidity.... This is a great but critical period, above all of a moral crisis. "145 [My italics.]

Le Corbusier saw his time not as part of a great continuum, but as a decisive change from the past.146 He clearly identified his time as one of crisis because, given the contemporary state of mind, one cannot understand "what is going on." Beyond the state of crisis, however, he was able to recognize that in past times change had not occurred in such a violent fashion, but rather had occurred as a "slow evolution." Written nearly two generations before Thomas Kuhn's work, Le Corbusier recognized almost exactly the same pattern of activity, though he himself discussed only the revolution of his own time.

Twenty years after Towards a New Architecture, Sigfried Giedion's publication of Space, Time and Architecture recognized a similar pattern of change. Giedion's book was more influential in this respect because it applied this pattern of change to several revolutionary events and stressed the fact that they did not originate so much from one person as from the period as a whole. This idea corresponded to Kuhn's later recognition that times of change are usually marked by simultaneous discoveries.

Giedion saw architectural history as part of a greater continuum and made reference to other intellectual disciplines in his introduction. His contributions to architectural history have been significant, though one must place his work in its proper context. Giedion was initially involved in the advancement of the modern architecture. He suggested as well that intellectual ideas appear to rise out of the age in which they were discovered, citing the example of the discovery of calculus, which was derived almost simultaneously by two different individuals.147 This recognition of simultaneous discovery followed throughout his book, and is particularly noteworthy because it was also used as an example of a paradigm shift in Kuhn's book. Giedion was also an interesting figure in architectural history because he so closely paralleled Kuhn's views prior to Kuhn's publication.148
Giedion began his history of architecture with the Renaissance and the invention of perspective. His description of its importance once again had Kuhnian overtones, though it was written almost thirty years earlier than Kuhn:

"Throughout the following five centuries perspective was to be one of the constituent facts in the history of art, the unchallenged canon to which every artistic representation had to conform.... To the fifteenth century the principle of perspective came as a complete revolution, involving an extreme and violent break with the medieval conception of space, and with the flat, floating arrangements which were its artistic expressions. "This principle came as an entirely new invention, but seldom has a new invention been so much in harmony with a basic feeling of an epoch. From the time of its discovery no hesitation can be observed in its application; it was used at once with complete confidence and sureness. Artists and scientists elaborated its secrets with a readily understandable excitement and pride."149

Giedion here identified all of the ingredients which Kuhn identified twenty-eight years later as the stages of paradigm shifts and normal science. Perspective was seen as a "complete revolution" which was adopted with "no hesitation." Artists and scientists then elaborated the basic idea (normal science), and it became the reigning canon for the next five centuries.

Giedion recognized another change which occurred with the industrial revolution. What had been the paradigm of the past no longer applied to the nineteenth century:

"In treating the nineteenth century we should arrive at unsatisfactory results if we adopted the approach we used for the previous period. A sufficiently comprehensive insight into the period could not be derived from the nineteenth-century monumental architecture... We shall
concern ourselves instead with the evolution, during this period, of new architectural potentialities, an evolution that proceeded anonymously and was born out of the depths of the age."\textsuperscript{150}

Once again, the changes were not seen as the result of particular personalities, but rather as the result of the "crisis" of the time.

Giedion's description of cubism and the general shift to the acceptance of a new understanding of space-time can easily be read as another example of a paradigm shift. First, he once again established that this was not solely the work of one man (or even the work of just Picasso and Braque), but rather of the epoch:

"Picasso has been called the inventor of cubism, but cubism is not the invention of any individual. It is rather the expression of a collective and almost unconscious attitude. A painter who participated in the movement says of its beginnings: 'There was no invention. Still more, there could not be one. Soon it was twitching in everybody's fingers. There was a presentiment of what should come, and experiments were made. We avoided one another; a discovery was on the point of being made, and each of us distrusted his neighbors. We were standing at the end of a decadent epoch.'\textsuperscript{151}

Secondly, he discussed the rapidity with which the shift occurred:

"This new representation of space [cubism] was accomplished step by step, much as laboratory research gradually arrives at its conclusions through long experimentation; and yet, as always with real art and great science, the results came up out of the subconscious suddenly."\textsuperscript{152} [My italics]

And finally, he suggested the "normal research" which followed it:

"Following upon the first efforts of the cubists, there came ... an awakening in various
countries. Common to these was an attempt to rationalize cubism or, as they felt necessary, to correct its aberrations."\textsuperscript{153}

These variations were done to help "fine tune" the theory as it was first presented. This, we will recall, was the specific purpose of the normal science which followed a paradigm shift in Kuhn's theory.

It seems apparent that the tempo of architectural change fit the general theory which Kuhn has used to explain scientific change. Certainly, we are led to discuss certain time periods (e.g., the Renaissance, or the beginning of the twentieth century) because they are significant periods in architectural history separated by less significant periods where little change has occurred.

\textbf{THE DEFINITION OF A SCIENTIFIC PARADIGM}

The similarity in tempo between science and architecture is very strong. Is it possible, then, to define an architectural paradigm as one does a scientific paradigm? Kuhn's original book gave a rather elusive definition of a paradigm, which he clarified in "Second Thoughts on Paradigms." In this essay, Kuhn made it clear that a paradigm could most closely be defined as a "scientific community."\textsuperscript{154} Kuhn stated:

"A scientific community consists, in this view, of the practitioners of a scientific specialty. Bound together by common elements in their education and apprenticeship, they see themselves and are seen by others as the men responsible for the pursuit of a set of shared goals, including the training of their successors....

"Such communities are characterized by the relative fullness of communication within the group and by the relative unanimity of the group's judgment in professional matters. To a remarkable extent the members of a given
community will have absorbed the same literature and drawn similar lessons from it."155

Because members of a community share a common literature, tracing an old paradigm, or community, may be possible by understanding their shared influences. Kuhn defined what holds a community together as the "disciplinary matrix" and divided it into three categories: Symbolic generalities, models and exemplars. Symbolic generalities were "those expressions deployed without question by the group," models were "preferred analogies" and exemplars "are concrete problem solutions, accepted by the group."

Though Kuhn recognized a hierarchy to paradigms, some affecting most scientists, others affecting only a few. He estimated, though, that most of these communities would probably have a membership of one hundred of fewer adherents.156

DEFINING AN ARCHITECTURAL PARADIGM

Kuhn's revised definition made it possible to determine whether or not the "spatial revolution in architecture" may be seen as either the development of an altogether new paradigm (from a preparadigmatic state) or the replacement of an old paradigm with a new one. In discussing this possibility, we must not depend too heavily on his suggested size for a scientific community since it is clear that some paradigms (the Newtonian of Einsteinian revolutions) affected a great number of subdisciplines and other paradigms affect only a few scientists in very specialized fields.

Most importantly, in order to define an architectural paradigm using Kuhn's definition, one must find a group of individuals who share a common "disciplinary matrix." Can we find either an architectural community (an architectural paradigm) which underwent a change during the early twentieth century (which would imply a paradigm shift within the community), or can we identify the establishment of an
architectural paradigm after the period of change (implying the establishment of an architectural paradigm from a pre-paradigmatic condition)?

The answer to the first question appears to be "no." If we can describe Frank Lloyd Wright, Le Corbusier and Theo van Doesburg as representative of those architects who were a part of creating new space conceptions in architecture, we must admit that they did not share what Kuhn would call a common body of literature. Wright and Le Corbusier both claimed to be original in their ideas and not derivative of others, though we have seen that they did have influences. Wright's work appeared to have no reference in common with either the work of Le Corbusier or that of van Doesburg.

Le Corbusier and van Doesburg were slightly more closely aligned in that they shared some common influence through the Cubist movement, though as we have seen they used it to drastically different ends. Le Corbusier's desire for change was ingrained in him from his early readings and his reason for change was stated as having to do with the age of industrialization. Through Ozenfant, Le Corbusier was exposed to the scientific dialog of the day, but did not take this in to the core of his architecture. Le Corbusier's architecture was a reaction to the influence of the Cubist movement and most likely derived from the early influence of Henri Provensal, who predicted revelation and change.

In a different vein, van Doesburg read the theories of the day much more closely than either Wright or Le Corbusier. He was exposed to the influences of Cubism through his relationship with Mondrian, but was also very involved with the Theosophists and took great interest in incorporating the influences of the Futurists and their new theory of space and time into his work.

If we try to establish these as part of a pre-paradigmatic search, we should find later a paradigm based on the searches of these three. Only in the largest sense can these three be said to belong to a common group, that of modern architecture. Though from
this work we cannot be sure whether or not one can define modern architecture as an architectural paradigm, we may be certain that if it can be defined as such, its definition must go well beyond a new conception of space, because, as we have seen, these three architects did not share a common perception of space. In all but the third case, the new conception of space was a side issue, a tool for the implementation of other ideas about architecture. If we then search for a paradigm created by these investigations, we find nothing of the scale suggested by the writings of Collins, Giedion or Zevi. It is also not possible to define this event as a paradigm shift (implying a previously existing paradigm which was replaced) because we can find no common "disciplinary matrix" on which they agreed.

The De Stijl movement appears the only likely candidate for an architectural paradigm from our survey, since it is the only movement of the period which defined its tenets as being specifically about space, mass and time. The points of agreement were clearly stated in "Towards Plastic Architecture" in 1924. By this same application of an architectural paradigm, one may define the Futurist movement and later CIAM as possible paradigms. In both instances the adherents published manifestoes defining their agreed upon assumptions ("disciplinary matrix") and acceptable methods.

Given our present discussion, however, we must conclude that it is erroneous to equate changes of individual perceptions of space with a "paradigm" of modern architecture based on space, as Giedion and Zevi would have us do. This suggests that the if change in the perception of architectural space is not enough to define an architectural paradigm, architectural histories based solely on changes in the perception of space are faulty in not representing the true intentions of the architects. This is not to say that such histories cannot or should not be constructed, but rather is to say that such histories present a one-sided view of the events of architecture. Manfredo Tafuri has called such stilted histories "operative criticism," criticisms given from a privileged
viewpoint to support a certain perspective which has been set in advance. As we have noted, perceptions of space are only tools for the implementation of other ideas about architecture. Constructing a history of architectural space perception is constructing a history of one of the tools of the field.

THE DIFFERENCES BETWEEN SCIENCE AND ARCHITECTURE

By evaluating some of the differences Kuhn found between science and art, we are able to clarify that appropriateness of a paradigm of modern architecture. In response to the application of his theory to art, Kuhn commented on his view of the relationship between the two fields in 1969. His discussion centered on four main differences he felt existed between the two worlds: differences in relationships to the public and the past, as well as differences in goals and the perceived number of solutions to a given crisis.

The most obvious difference between science and art was that they differ in their goals. According to Kuhn, the goal of scientific research is the solution to a technical problem, in which aesthetics plays a role only in arriving at a solution. On the other hand, the goal of art is specifically the aesthetic and the technical solution is only the means to that end. In architecture at least, this dichotomy is not quite so clear. The architecture of Le Corbusier sought a solution to a technical problem (a machine for living in) and advocated that the solution would, in itself, be aesthetic:

"If we eliminate from our hearts and minds all dead concepts in regard to the house, and look at the question from a critical and objective point of view, we shall arrive at the 'House-Machine,' the mass-production house, healthy (and morally so too) and beautiful in the same way that the working tools and instruments which accompany our existence are beautiful."
The second difference -- the relationship to the public, is clearer. Art, he argued, has a public audience and can be shown in museums and galleries while it is still an active part of the discussion in art. The museum of science are, however, is a different affair where one sees only "dead" science and one rarely sees a scientist there for inspiration. One may debate the generalizations in either discipline, but one surely can debate it in architecture. The most obvious example of this was the creation of CIAM, which, according to the public, set itself off from the public and deigned to dictate for itself what was and was not architecture.

The most difficult of the differences is that of the past. It is much easier to construct the derivation of scientific schools of thought and theories because they necessarily replace one another. According to Kuhn, a new paradigm cannot coexist with the paradigm it was created to replace. Because scientific paradigms can be described as gestalt switches and usually involve a new vocabulary and a new group of adherents, one can readily see, within a certain frame of reference, where or when a paradigm shift has occurred. In architecture, if we can say that paradigm shifts do exist, we must admit that a new paradigm and the one it replaces do not appear to be mutually exclusive. Architects may continue to build in the manner of their choosing whether or not a new paradigm has been developed. The last of the differences, that there is a single best solution to any perceived problem in science, but not in architecture, is related to the fact that paradigms do not appear to replace one another. If one assumes many solutions for a problem, one must accept coexistent solutions or paradigms.

As we have seen, there appear to be exceptions to the differences Kuhn found between art and science when one looks at architecture. One must then ask the question whether the perceived differences between science and architecture are great enough that a parallel theory of paradigms and paradigm shifts cannot be applied effectively to
architecture. As we have noted, such groups as De Stijl and CIAM appear likely candidates for architectural paradigms.

Science is easily subdivided into specialties and subspecialties which all adhere to slightly different sets of paradigms. (i.e., the paradigm under which a microbiologist operates is significantly different than that under which a structural engineer operates, though both at some level would admit an adherence to Einsteinian and quantum physics.) The field of architecture has never had such clear cut subdivisions as in the sciences, yet at some level it appears that these subdivisions (such as De Stijl) do exist. In order to more fully examine the appropriateness of Kuhn's theory in architecture, two steps should be taken.

One should attempt a more thorough examination of the divisibility of Architecture. Is it possible that subdivisions exist within architecture defined by the conference and symposium circuits which exist? By first examining the subdivisibility of the field and then examining the possible "architectural communities" for Kuhnian-like behavior, one may be able to more clearly evaluate the applicability of an architectural paradigm.

Such an investigation is beyond the scope of this thesis and is suggested only because of the appearance of Kuhnian-like "architectural communities." Only after such an investigation can we determine to what extent a theory of paradigms and paradigm shifts may provide a fruitful perspective for evaluating architectural change, and more specifically, clarify the differences which may exist between science and architecture.
CONCLUSION

The opening quote by Peter Collins certainly holds true. Architects today do consider "that modern buildings possess spatial relationships of a quite different order from those possessed by buildings of the past."

He is equally accurate in what he does not assert: that the different order of spatial relationships in a unified perception of space. The work of Frank Lloyd Wright, Le Corbusier and Theo van Doesburg represent different understandings of architectural space.

Wright's spaces overlap and intersect in such a way that they can be read as interpenetrating each other. His spaces were allowed to breach the building envelope and connect the interior and the exterior. His volumes were, for the most part, horizontal extensions out into space.

Le Corbusier's spatial representation was quite different in that he created pure spatial volumes which could be read against a datum and were contained within the building envelope. The surface of his building envelopes allowed yet another reading of spaces, as he suggested a hierarchy of the spaces one find on the interior which was very different from the spaces created on the interior.
Theo van Doesburg’s perception of space was different still. He challenged himself, through his exposure to intellectual circles, to apply the theories of the day to a new architecture. Of the three, van Doesburg was the only to claim spaces, volumes, masses and planes as the only concern of architecture.

As we have seen, the work of these three does not support a view of a new unified perception of space. In addition, the influences on their work and their stated reasons for building such work do not suggest such a theory. Instead, they suggest a different reading of the role of space in architecture. In each case but the last, the role of spatial representation was only to aid in the representation of the architect’s ideas about architecture.

Because these architects do not appear to share a common "disciplinary matrix," the changes of spatial perception in architecture do not support an interpretation of these events as a paradigm shift. The theories of the time do not indicate that there was a switch from one type of spatial interpretation to another specific interpretation of space. Instead, this research has uncovered two likely architectural paradigms, which may be investigated further by others in an attempt to fully understand the advantages and limits of applying a Kuhnian theory of paradigm shifts to architecture. The results of this research do not negate the possibility of such an application.

Based on such results, revisionist architectural histories, such as Giedion and Zevi, do not appear to offer objective views of the development of architectural history. These histories are written with a bias towards architectural conceptions of space which appear to be unified. The work of the three architects studied does not support such a view of the architecture of the early twentieth century, and thus calls into question the application of this idea to all of architectural history.

What this research does suggest is that architectural perceptions of space at the beginning of this century were derived only in an attempt to represent other ideas in
architecture. This differs significantly from the art of the period, which did directly take on the means of the representation and understanding of space as a major concern in the new movements of the age. Such an interpretation leads one to the conclusion stated earlier, that the use and representation of space in architecture is only to be seen as a tool for the implementation of other ideas about architecture. To define the history of architecture as the history of spatial conceptions, as Bruno Zevi did, is to create a limited understanding of the field. It is to write a history of architecture based on the tools of architecture and not on the architecture itself.
APPENDIX A

1824 Gauss attempts to show a non-Euclidean geometry.
1826 Lobachevsky develops a non-Euclidean geometry.
1846 E. A. Poe claims "Space and Duration ARE ONE." in *Eureka*.
1854 Riemann's lecture on non-Euclidean geometry.
1859 StereoScope invented by Oliver Wendall Holmes.
1862 Manet's *Music in the Tuilleries*.
1865 *Alice's Adventures in Wonderland* published by Lewis Carroll.
1867 Publication of Riemann's lecture.
1869 Frank Lloyd Wright born.
1872 *Through the Looking Glass* published by Lewis Carroll.
1876 Telephone invented by Alexander Graham Bell.
1877 Eadweard Muybridge begins motion photography.
1880's E. J. Marey creates Chronophotography.
1883 Theo van Doesburg born.
1884 *Flatland* published by Edwin A. Abbott.
1887 Charles-Édouard Jeanneret (Le Corbusier) born.
1889 Bergson publishes *Time and Free Will*.
1892 Claude Monet paints Rouen Cathedral series.
1893 W. H. Winslow house by Frank Lloyd Wright.
1895 H. G. Wells publishes *The Time Machine*.
1898 X-rays discovered by William Röntgen.
1898 Henri Poincaré publishes "*La Mesure du Temps*".
1901 Emma Martin house by Frank Lloyd Wright. (Altered in 1907.)
1903 Powered flight by Wilbur and Orville Wright.
1903 Henri Poincaré publishes "Science and Hypothesis."
1903 E. Jouffret publishes *Traité élémentaire de géométrie à quatre dimensions*.
1904 H. Provensal published *L'art de demain*.
1905 Einstein's Special Theory of Relativity.
1907 Maison Fallet by Jeanneret (Le Corbusier).
1908 *Les Desmoiselles d'Avignon* painted by Pablo Picasso.
1908 Henri Bergson publishes *Creative Evolution*.
1908 Minkowski's statement on the fourth dimension -- space-time.
1908 Robie house by Frank Lloyd Wright.
1909 First Futurist manifesto published by F. T. Marinetti.
1910 First Wasmuth publication of Frank Lloyd Wright's work.
1911 First Cubist exhibition at Salon des Independents.
    G. Apollinaire uses term "fourth dimension" in discussing
    Cubist work.
    Rutherford's atomic theory published.
1912 Du Cubisme published by Gleizes and Metzinger.
    First Futurist exhibition in Paris.
1913 Bohr's atomic theory.
    Freud publishes Totem and Taboo.
1914 World War I.
    Paul Frankl publishes Principles of Architectural History.
1916 Einstein's General Theory of Relativity
1917 Freud's Introduction to Psychoanalysis.
    van Doesburg begins rectangular painting after Mondrian.
1918 Ozenfant & Jeanneret's publishes Après le Cubisme.
1919 General Theory of Relativity confirmed by Eddington.
    Rutherford proves subatomic particles.
    Bauhaus founded.
1920 L'Esprit Nouveau begins publication.
1921 De Stijl founded.
1923 Le Corbusier's Towards a New Architecture.
    Private house designs by van Doesburg and van Eesteren.
1924 van Doesburg publishes "Toward Plastic Architecture."
    Schröder house by Gerrit T. Rietveld.
    Louis De Broglie posits particle/wave duality.
1926 Heisenberg Uncertainty Principle.
1927 Villa Monzies-Stein at Garches designed by Le Corbusier.
NOTES:

2 Oud, page 87.
3 Kern, page 1.
5 Giedion, page xxxvii.
6 Zevi, page 32.
7 Zevi, page 223.
8 Connors, page 19.
9 Rowe, page 168.
10 Rowe, page 170.
11 Blotkamp, page 4.
12 van Doesburg, 1922, page 128.
13 van Doesburg, 1924, pages 142-144.
16 Jammer, page 146.
17 Poincaré quoted in Pais, page 126.
18 Pais, page 127.
19 Henderson, page 15.
20 Abbott, page 88.
21 Henderson, page 25.
22 Wells, page 2.
23 Henderson, page 36.
24 Henderson, page 56.
25 Bergson, page 110.
26 Scharfstein, page 9.
27 Bergson, page 95 noted in Lindsay, page 123.
31 Einstein, page 30.
32 Coveney, page 93.
33 Minkowsky in Annalen der Physik 47: 927(1915) quoted in Pais, page 152.
34 Coveney, page 80.
35 Coveney, page 115.
36 Barthes, page 93.
37 Barthes, page 96.
38 Shlain, page 98.
39 Eastlake, page 52.
40 Holmes, page 75.
41 Holmes, page 80.
42 Darrah, page 6.
43 Osborne, page 29.
44 Henderson, 161.
45 Henderson, page 161.
46 Bragaglia, page 41.
47 Bragaglia, pages 40 and 43.
48 Bragaglia, page 39.
49 Shlain, page 104.
51 Shlain, page 108.
52 Kern, page 141.
53 Schwartz, page 22.
55 Henderson, page 81.
56 Henderson, page 44.
57 Henderson, pages 89 and 101.
59 Gray, page 73, with reference to Olivier, Picasso et ses amis, page 138.
60 Henderson, page 59.
61 Gray, page 73.
62 Metzinger interview quoted in Henderson, page 83.
63 Gleizes and Metzinger, page 36, quoted in Henderson, page 90.
64 Henderson, page 91.
65 "Picasso and Braque: Pioneering Cubism."
67 Le Becq.
68 Henderson, page 91.
70 Kern, page 119.
71 Boccioni et al., 1910a, page 26.
72 Boccioni et al., 1910b, page 28.
73 Boccioni, 1913b, page 88.
74 Boccioni, 1914, page 177.
75 Apollonio, pages 12, 13.
76 Apollonio, page 14.
77 Boccioni, 1913a.
78 Boccioni, 1914, page 173.
79 Boccioni, 1913a, page 107.
80 Boccioni, 1913b, page 89.
81 In paging through the issues of Lacerba, there were no recognizable references to either the names of scientists or to "Space-time" or the like. I speak no Italian, so I by no means consider this an authoritative statement.
Boccioni et al., 1910b, page 27.
Boccioni et al., 1910b, page 27.
Henderson, page 108.
Boccioni, 1913c, page 92.
Boccioni, 1913c, page 93.
Boccioni, 1912, page 52.
Boccioni, 1913c, page 94.
Banham, page 136.
Giedion, 1941, page 396.
For a list of these articles, see Appendix B of Henderson.

Though referred to as "gifts," they were a series of objects designed to teach the child about Life, Knowledge, and Beauty. The third through sixth gifts were wooden cubes which had been subdivided in various ways to create building blocks for the child. For a more complete discussion of these blocks and their influence on Wright, refer to MacCormac.

MacCormac, page 104.
Wright, 1908, page 11.
Wright, 1908, page 13.
Wright, 1908, page 18.
Banham, page 145.
Oud, page 85.
Oud, page 87.
Mumford, page 74.
Collins, page 286.
Turner, page 22.
Turner, page 16.
Turner, page 20. No specific citation is given for the Provensal quote.
Originally published in *L'Esprit Nouveau*, the issues of which were undated.
Henderson, page 301.
Ozenfant, page 8.
Henderson, page 334.
von de ven, page 185.
Ozenfant, pages 136 to 144.
von Doesburg, 1924, page 142 - 144.
Baljeu, page 16.
Baljeu, page 20.

An essay by Mondrian in the first issue of *De Stijl*, quoted in Henderson, page 318.
October, 1918, in *De Stijl*, vol. II, 2, December 1918, pp. 23 - 4, as quoted in Baljeu, page 109.

Baljeu, page 29.

Berlage, page 82.

van Doesburg, 1922, quoted in Jaffé, page 154.

Kuhn defined a paradigm as a "universally recognized scientific achievement that for a time provides model problems and solutions to a community of practitioners."

Page viii. He later redefined this definition in "Second Thoughts on Paradigms."

Kuhn, 1969a, page 4.

Ibid., page 35.

Ibid., page 5.

Ibid., page 92.

Ibid., page 85.

Ibid., page 47.

Ibid., page 48.

Ibid., page ix.

Giedion and Zevi.

Focillon, page 53.

Ibid., page 53.

Ibid., page 53.

Ibid., page 54.

Ibid., page 55.

Ibid., page 57.

Giedion, quote on page 212, also see footnote on page 213. Giedion's reference is to "L'Architecture de l'avenir," in *Revue generale d'architecture*, page 27.

Kuhn, pages 18 and 19.

Quoted in Banham, page 27.


Ibid., page 7.

Ibid., page 271.

This idea derived from Provensal.

Giedion, page 22.

Giedion was very involved in one of the modern movements, CIAM. In this respect, his history must be taken as one in support of this movement. In addition, Giedion was affected by his mentor, Heinrich Wölfflin, who initially was an adherent of the idea that architecture was corporeal form. (van de ven, page 94.) While Giedion must be taken in the context of these associations, he is still noteworthy for having noted a very similar approach long before Kuhn.

Giedion, page 31.

Giedion, page 164.

Giedion, page 435, no reference is made to the author of the quote.

Giedion, page 437.

Giedion, page 439.
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