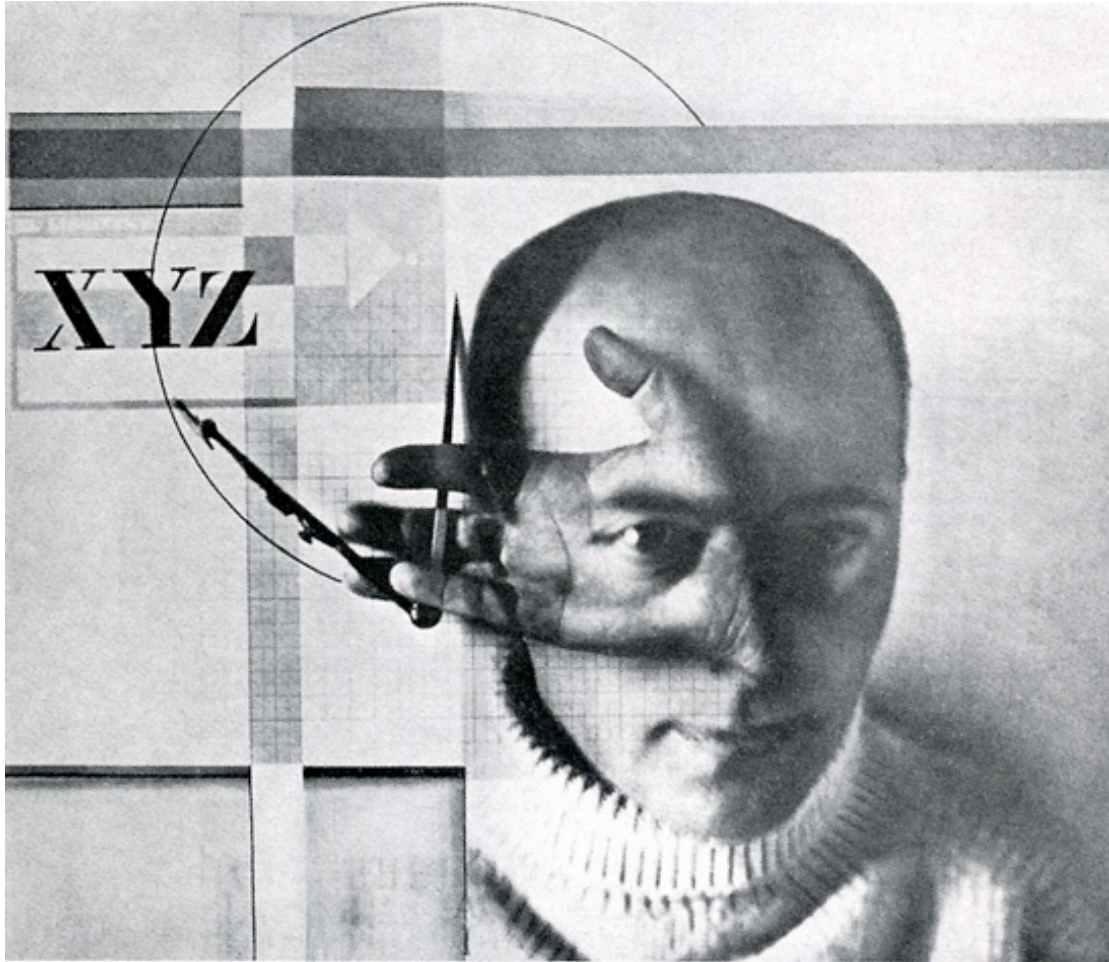


Reasoning in Architecture

About the Diagrammatic Nature of Thinking with Real and Imagined Objects



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Delft University of Technology,
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January 21, 2009

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Cover page image: *The Contstructor*, photomontage self-portrait by El Lissitzky, 1925

0.1 Acknowledgements

The nature of a graduation project is that it ends with graduating, although that this event mark an end point for this project, it is not the termination of the development of ideas and research, there is so much more in this work that can be developed, lines of thought that need elaboration. When I think about the 'never ending' nature of this work, the graduating moment seems artificial, although deadlines like these enforce that my ideas become manifest on paper.

In working on this project I have encountered a lot of firsts. It was my first time writing a text of such an extensive size, in doing this I learnt a lot about writing, about language, about structuring your thoughts and articulating ideas and clarifying arguments. The other first was that also intellectually I went into a lot of previously unknown territory, in an effort to bring the lessons I learnt in these unknown territories (for architects anyway) back 'home' again. In the maiden voyage, that this Master graduation project was, both technically and intellectually, I have been tremendously supported. Although I want to note that all errors and unclarities in this work are entirely my own.

First of all I would like to thank the people who have guided me through this project on behalf of the Delft University of Technology. John Heintz for accepting my graduation project at Explorelab, bearing with me through the various transformations this project has undergone in the past one and a half year, and for the relentless sharp criticisms on my writings. Christian Illies for asking me the right questions, which pushed me to think harder and articulate more precisely. Peter Kroes for continuing Christian Illies philosophical guidance. Hans van Dijk for bringing this project home to architectural discourse, for handing me the right texts and references. Not only did Hans gave his guidance in this particular project, but I want to thank him also for his continuing support and consult throughout my time as a student at the Faculty of Architecture organising extra-curricular activities with D.B.S.G Stylos and otherwise. Besides these individual staff members of the university I would like to thank everybody in Explorelab for a wonderful experience, the supportive atmosphere, and the many conversations over coffee and other beverages with fellow students and staff members.

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Besides the direct support in the form of feedback and criticism on this project I have received endless support my entire career at this university (since 2000) from my family and friends. Thank you! You know who you are.

0.2 Preface

El Lissitzky's self-portrait, *The Constructor* made in 1925 (on the cover), captures many of the ideas that are treated in this writing. One of the interesting aspects of this image is that it is a self-portrait of an architect, or perhaps a self-portrait of *the architect* in general. One of the main problems with many of the methods contrived for design is that they provide architects with methods that often seem to rigid and prescriptive to them, or to superficially informing them of something they already know. Architects in general don't like to hear what they ought to do or think. At the outset of this research this was acknowledged and the aim of this research is not to provide a manual, but to provide insight. For myself as the writer of this work, I found many new insights through the research I did. Insights in my own thinking as architect, with many moments of recognition while reading Schön, Hawkins, Aristotle, Peirce and many other works.

Besides many moments of surprise and insight for myself, this will hopefully be the same for other architects and designers reading this work. This constitutes in my opinion the main joy of this piece of writing. Besides the fun there is also function, this is very simple: This work I believe hands architects and designers a vocabulary that grasps the nature of their thinking. Because one needs to name ideas before one can exchange them and develop them. Some of the introduced ideas and their associated names hopefully lessen some of the Babylonian confusion that is often present in architectural discourse. Thus, in order to lessen the confusion this constitutes the paradoxical gesture of adding (new) words to a discipline that is already heavy of neologisms and other many other -isms.

Edwin Gardner

21-1-2009, Delft

0.3 Research Summary

0.3.1 The Research Goal

The primary goal of this research is to obtain a deeper understanding of the thought processes in architectural design, especially concerning creative and intuitive thinking. In an effort to go beyond the mystifying veil that often covers the design process of architects, in this project it is the aim to explain the thought processes in architectural design as modes of reasoning. The secondary goal follows from the notion of understanding architectural design thinking as a form of reasoning. Within architectural discourse there is often a Babylonian confusion about architecture's legitimations, narratives and concepts. This is the result of the rich variety of ideas about architecture that are spread through the array of schools and offices, and of a lack of common understanding what the core of the architectural profession is. The last point is addressed through this research by an effort to constitute on a foundational level, the level of reasoning, a common core, a *lingua franca*, around which all the exotic varieties of architecture can develop their own discourses. Very much in the same way that human intelligence principally functions the same in every human, but that trains of thought and association can be radically different, while the entire human race on a fundamental level shares the same anatomic functions of the brain.

0.3.2 The Research Problem

As indicated, the effort of explaining the architectural design process as a form reasoning is rooted in the idea that at a fundamental level the type of thinking process in the mind are similar in every design process. This is a bold statement. It has been tried before to write down unifying theories for all architectural design processes and it has failed. The problem lies in on what level one chooses to propose a unitary theory. Eventually we are all stardust, we are built up of atoms, but this is a too fundamental level obviously, from this we can learn nothing meaningful about architectural thinking. The same goes the other way around, when stay too close to the surface of the design process, every design process seems different. This is why the right level has to be found and focussed on. Here also lies a problem in most contemporary research of the design process; it stays too close to the surface of analysing behaviour. This limits research to what we can only see, while here we want to go beyond this. The chosen level on which this research is performed is thus on reasoning and intelligence. Explaining the workings of reasoning is the discourse of philosophers, explaining the workings of intelligence is the discourse of the cognitive sciences, which involves a psychologists, computer scientists and brain researchers. This results in quite a variety of theoretical frameworks, to compare, find similarities and consolidate these is the challenge.

0.3.3 The Research Method

The research is a theoretical comparative literature research, and mainly revolves around the original ideas of three individual:

1. Donald A. Schön (1930-1997) a design researcher, but trained as philosopher who succeeded in describing how designers think in a way that designers recognise the processes he is describing. What makes Shon's work interesting are the categories he introduces. These are fundamental descriptions how a designer engages the design activity. His categories are open but still defined enough for designers to recognise the fundamental process they are involved in. It describes an iterative process, but does not

specify tasks, design phases or step from beginning to end. Schön theory is presented in his book *The Reflective Practitioner* (1983)

2. Jeff Hawkins (1957) is a computer architect turned neurologist. He is interested in making truly intelligent machines, but believes one can only do so when we understand how the brain produces intelligence. He states that in the cognitive sciences intelligence is judged by the wrong parameter: behaviour. According to Hawkins this is only a manifestation of what intelligence really is, behaviour is but the surface. Hawkins puts forward a theory that intelligence is determined by prediction. According to him the brain makes continuous predictions about the world it 'sees' through its senses. It makes these predictions by analogy to the past, to what is already stored in our memory. Hawkins' theory is presented in his book *On Intelligence* (2004)
3. Charles Sanders Peirce (1839-1914) was a philosopher, logician and mathematician. Peirce was interested in where new ideas came from, how the mind was able to put forward fruitful ideas, and in that way was instrumental in the development of knowledge. Peirce believed that deductive and inductive reasoning were not adequate in describing how this worked, thus Peirce developed a third mode of reasoning, abduction, with which he tried to clarify processes of invention and discovery. Another theory of Peirce is also of importance more specifically for the work of architects, that of diagrammatic reasoning. He developed the concept of diagrammatic reasoning in the context of explaining creativity in mathematics, but it can also give us a deeper insight in how architects reason through making drawings and models. Because like mathematics also architectural design is mediated activity. Peirce's theories were developed over his entire career, publishing many papers and articles. For this research the explanation of Peirce's theories is based on the readings of Michael H. G. Hoffmann and Sami Paavola.

Besides these main protagonists, Aristotle's *Rhetoric* plays a significant role in describing the nature of reasoning in architectural design.

The comparative literature research consists of two distinct phases.

1. The first phase (chapter one and two) follows from the fact that the field of Design Methods and Artificial Intelligence share a similar development of principles concerning how they believe thinking works. This is captured in how the relation between knowledge and thinking relate to each other. Where at the inception of Design Methods and Artificial Intelligence, both in the 1960s, knowledge and thinking were deemed categories that needed to be separated. Thinking was thought to have an instrumental role, applying objectively obtained information in the right fashion and in the right context. The development in both fields is similar in that in the 1980s there grows an acknowledgement that the separation of knowledge and thinking is problematic, as Schön shows for design (and other practices) and Searle shows in Artificial Intelligence. While Schön also proposes an alternative theory, a different epistemology of practice, Hawkins' work proposing another way of dealing with intelligence than behaviour comes 20 years later. Although some of the notions in Hawkins' work are preceded by the Neural Networks research field which acknowledges the indivisibility of knowledge and thinking, which is also strongly present in Hawkins' theory. The parallel development in ideas about design thinking and machine as well as human intelligence, makes a comparison possible.
2. The second phase (chapter two and three) introduces reasoning. Starting with an overview of various modes of reasoning (induction, deduction and abduction) and

researching how powerful they are in explaining the thinking in the architectural design process. One of the important notions here is that reasoning is considered in more general terms not merely as syllogistic reasoning, i.e logic. How Aristotle deals with reasoning in *'The Rhetoric'* opens up possibilities of drawing analogies between thinking in the architectural design process and rhetorical deduction and induction. The final operation of chapter two is to further elaborate the consolidated model resulting from the similarities between Schön and Hawkins, as forms of reasoning. Further articulation of how reasoning works in relation to the specific mediated nature of the architectural design process follows from Peirce's diagrammatic reasoning in chapter three.

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Chapter 1

Prologue: The Indivisibility of Knowledge and Thinking

What the making of intelligent machines and the effort of describing how designers think have to do with each other.

Let us first simplify the question a bit, what does an intelligent machine have in common with a designer? If we assume that a machine could be genuinely intelligent, than what the machine and the designer would have in common is that they can think (taken that intelligence is a prerequisite for being able to think) and history has shown that we have an equally hard time figuring out how to make a machine intelligent and explaining how designers think. Most importantly the theories that were developed since the 1950s about how to model intelligence for a machine and how designers should think have a lot in common and are built on the same epistemological framework of positivism and technical rationality. Besides a shared intellectual basis, there is also a shared protagonist, Herbert Simon. Simon was an early pioneer in developing Artificial Intelligence systems (*Logic Theorist* in 1955 and *General Problem Solver* in 1957 both with Alan Newell) and also developed what became the definitive framework for a universal method of design, which was aimed at turning design into a science of the artificial that he described as: “the discovery of a partially concealed pattern; in a rigorous and objective way. Design science could then become ‘a body of intellectually tough, analytic, formalizable, partly empirical, and teachable doctrine about the design process’” (Simon, 1969) This theory that Simon presented in his 1969 book the *Sciences of the Artificial*, was the culmination of a decade of discourse on Design Methods and a collective effort to “scientize” design (Cross, 2006)

1.1 The Promise of The Machine

How the computer shaped our modern notion of thinking and intelligence

It all begins with the emergence of machines effecting modern life on every level, where the first Industrial Revolution was confined to the factory hall and the people’s most common and direct encounter with the machine was the automobile. After the Second World War the machine started to invade our homes:

“most of them make their point of impact on us in the form of small machines -shavers, clippers and hair-dryers; radio, telephone, gramophone, tape recorder and

television; mixers, grinders, automatic cookers, washing machines, refrigerators, vacuum cleaners, polishers. (...) A housewife alone often disposes of more horse-power today than an industrial worker did at the beginning of the century. This is the sense in which we live in a Machine Age. We have lived in an Industrial Age for nearly a century and a half now, and may well be entering a Second Industrial Age with the current revolution in control mechanisms. But we have already entered the Second Machine Age, the age of domestic electronics and synthetic chemistry, and can look back on the First, the age of power from the mains and the reduction of machines to human scale, as a period of the past.”

(Banham, 1960).

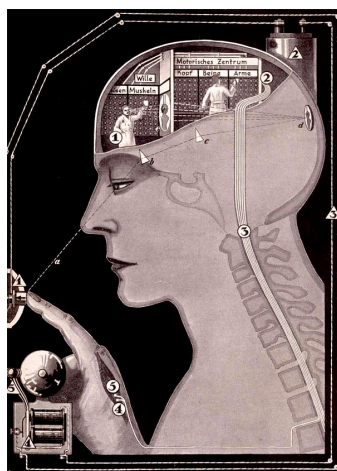
This is what Reyner Banham wrote in the introduction of his 1960 book the *Theory and Design in the First Machine Age*

While Banham recognises the importance of the impact of the ever shrinking machine on society, he opted for the television as “the symbolic machine of the Second Machine Age” and not the computer (which in 1960 were still scarce and usually only accessible at research institutes, and they were very big, ‘room-sized’ machines). What Banham perceived correctly was the spreading of mechanical processes and organisation well beyond the domain of technology to how we deal with thought itself: “our explorations into the nature of information have made it possible, on the one hand, to set electronics to work to take the drudgery out of routine thought, and on the other hand to tailor human thinking to suit the needs of some narrow-minded power-lite” (Banham, 1960) Banham recognised the dangers of some of the Machine Age enthusiasms and his introduction gives a good feel for the *zeitgeist* of this new age he describes at the dawn of the sixties. This is also the main reason I cite Banham here, because he correctly registers the dynamics of the time in which the industrial machine is replaced by domesticated electronic machine (which later turned out to be the computer) and where design thinking is tailored to suit a systematic and rigorous process.

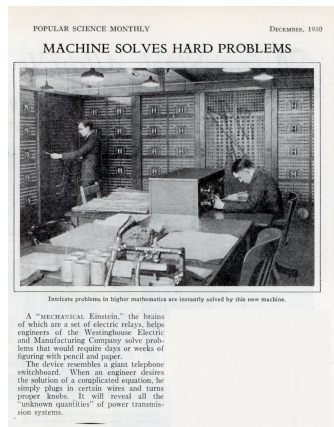
As Banham shows, it starts with the machine, and to return to our main question: “What does the making of intelligent machines and the effort of describing how designers think have to do with each other?”

How do you make an intelligent machine? Nobody knows for sure, because a truly intelligent machine hasn’t been made yet. There are enough machines that can do smart and impressive things, things that a human could not do or would take a human excessive amounts of time and energy. Although machines can do a lot of things much better than humans doesn’t mean that the machine does something intelligently. Interestingly enough so called intelligent machines have a hard time with the simplest of things, at least simple for us humans. “Even today, no computer can understand language as well as a three-year-old or see as well as a mouse.” (Hawkins & Blakeslee, 2004)

The project of making machines intelligent was the consequence of a theoretical machine that Alan Turing called the ‘universal machine’ (Turing, 1936) but that now has become real and we all know as the computer. About the universal machine Turing said in 1947 “It can be shown that a single special machine of that type can be made to do the work of all. It could in fact be made to work as a model of any other machine.” (Turing, 1947) Later in 1950 Turing thought computers could not only be other machines, but that a machine could also emulate the brain, and thus in other words that machines could be made intelligent. How a machine could emulate



(a) One of Fritz Kahns body machines he drew in the 1920s



(b) A page from the magazine Popular Science, Dec. 1930



(c) A page from the magazine World Of Science, Jan. 1958

Figure 1.1: Machines and later computers have since their invention always been the prime analogy for describing and understanding the nature of the brain, and thus the main inspiration for those who were and are after emulating it

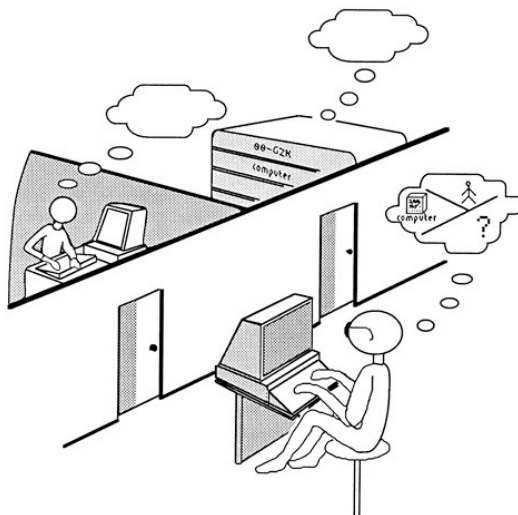


Figure 1.2: A representation of Turing's intelligence test

the brain he didn't know, and what intelligence was he also didn't know. Turing worked around the problem of defining intelligence itself through what we have come to know as the Turing Test (Turing, 1950): "if a computer can fool a human interrogator into thinking that it too is a person, then by definition the computer must be intelligent. And so, with the Turing Test as his measuring stick and the Turing Machine as his medium, Turing helped launch the field of AI. Its central dogma: the brain is just another kind of computer. It doesn't matter how you design an artificially intelligent system, it just has to produce humanlike behavior." (Hawkins & Blakeslee, 2004) The landmark event that is generally seen as the birth of the AI field was in the summer of 1956. For a whole month a group of scientists gathered for a research project on Artificial Intelligence at Dartmouth College (U.S.A). Amongst these scientist were: John McCarthy, Marvin Minsky, Herbert Simon and Allen Newell, who after this gatherings started AI research labs at various universities across the U.S. (MIT, Stanford and Carnegie Mellon)

Around the same time that the field of AI emerged, the field of Design Methods emerged. The Design Methods movement was interested in establishing a more objective and universal approach for the design process in which judgement wasn't determined merely by intuition and rules of thumb. They wanted to articulate a universal method of design that could produce a fitting solution to any given problem. Thus depending on the problem given, the solution could be a certain building, bottle or radio. To be able to do this it was important to replace subjective design experience and intuition with an objective method that could determine the optimum design solution in any case. The designers final judgement would consist of a technical decision to prevent errors that would result from choices based on intuition and subjective experience.

1.1.1 The Rationale of the Machine

The computer as an embodiment of positivist epistemology

What both Design Methods and Artificial Intelligence share is that they are based on a positivistic paradigm. "Positivists hold that science is the only source of knowledge about the world, and that this objective knowledge of reality can be extended to control technology, human behavior and society" (Dorst, 1997). Science as a source of knowledge in this case is "all knowledge regarding matters of fact is based on the 'positive' data of experience, and that beyond the realm of fact is that of pure logic and pure mathematics"¹, thus the only thing existing beyond factual reality is logic and mathematics. Schön explains what this means for how (design) professional should think in practice: "The positivist epistemology of practice rests on three dichotomies. Given the separation of means from ends, instrumental problem solving can be seen as a technical procedure to be measured by its effectiveness in achieving a pre-established objective. Given the separation of research from practice, rigorous practice can be seen as an application to instrumental problems of research-based theories and techniques whose objectivity and generality derived from method of controlled experiment. Given the separation of knowing and doing, action is only an implementation and test of technical decision." (Schön, 1983)

The fundamental scheme of the computer is the embodiment of these positivist dichotomies described by Schön. The computer separates 'knowledge' and 'thinking' in the components of 'memory' and 'processor'. In the memory you can only passively store data, and the processor can only move the data around. The computer, first described in theory by Turing as the 'universal machine', consists of two components. The first component is something on which symbols

¹Encyclopedia online Britannica: <http://www.britannica.com/EBchecked/topic/471865/Positivism>

could be written, read and erased. Turing imagined this as an endless piece of *tape* on which this could be done. In our modern day computer we call this memory. The second component is something that can write, read and erase on the tape described by Turing as the *head*. This head knows where and what it needs to write, read or erase something because it is connected to a finite list of operations that defined what to do for every symbol it encounters. This is more or less analogous to what we in our modern day computer call the Central Processing Unit (CPU).

The computer is a universal means which can be used to reach any end, a universal machine. The computer knows nothing, it only has a set of instructions of what to do when it encounters something in its memory. The computer only needs some input and a program (which it both finds in its memory) to do its work. The notion drives the project of establishing a universal design method, a singular method that depending on what the input is can generate any appropriate design solution.

1.1.2 Designers Emulating Machines

The need for new ways of designing

‘A trend towards more logical and systematic methods of design has been evident throughout the 1950’s. In many cases they have appeared as the result of new technical developments such as computers, automatic controls and systems. During the same period there have been attempts to give more scope for imagination and creative thought in design under such titles as ‘creative engineering’ and ‘brainstorming’.” (Jones & Thornley, 1963)

This is the opening paragraph of the lecture of J.Christopher Jones, held at the conference held on the 19th till 21st of September 1962 at Imperial College in London titled *Conference*

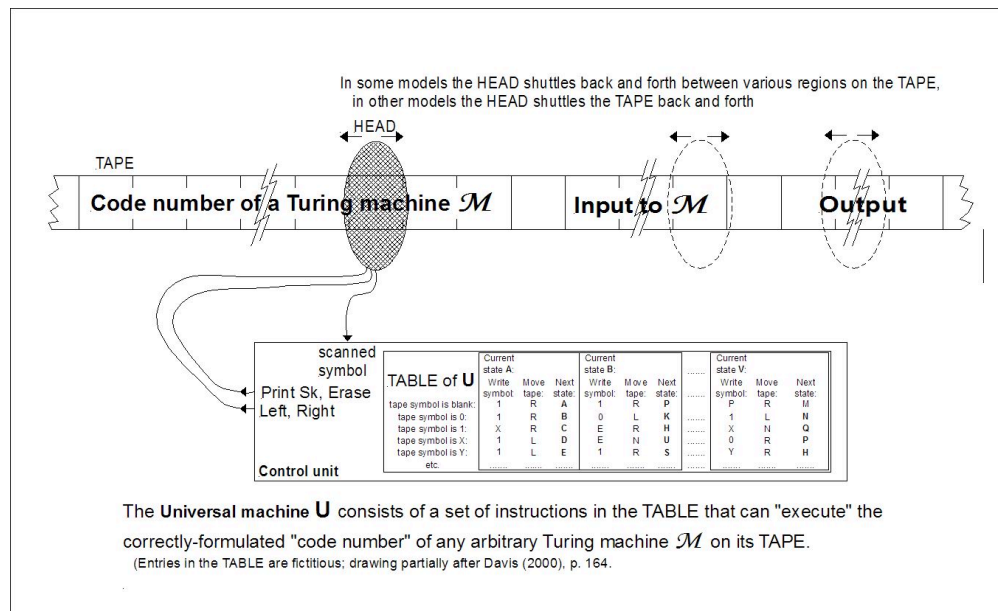
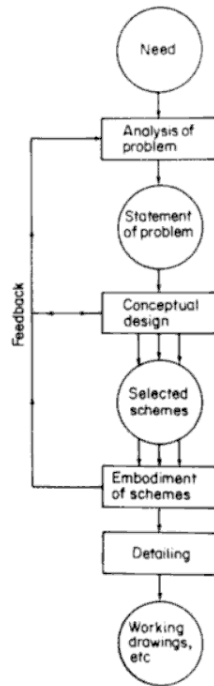
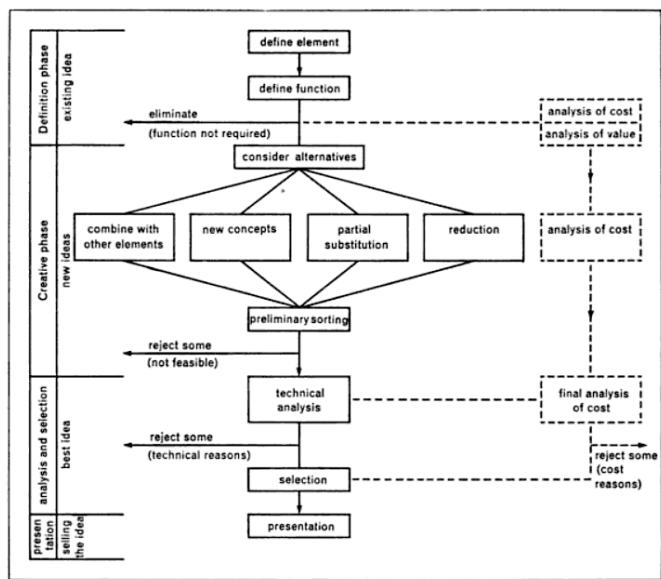


Figure 1.3: a scheme representing the Universal Machine as described by Turing



(a) Scheme from: *Conceptual Design for Engineers* by M.J French (1985)



(b) Scheme from: *Design Methods; Seeds of Human Futures* by J.C.Jones (1970)

Figure 1.4: Two schemes representing different aspects of Design Methods, (a) is an general representation of the entire design process, and (b) a value analysis method to reduce product costs.

on *Systematic and Intuitive Methods in Engineering, Industrial Design, Architecture and Communications*, a conference “believed to be the first to be concerned with the methods, processes and psychology of the Design act” as Peter A. Slann writes in the foreword of the conference proceedings (Jones & Thornley, 1963). “The Conference (...) was the outcome of a discussion which took place a few years ago when I first met Christopher Jones. Then as now, we were particularly keen to seek out and establish systematic methods of problem solving, especially those problems associated with design. We also sought a means by which design could be taught as a creative process that could be aided by a systematic process of conscious thought, integrating experience with academic knowledge whilst at the same time keeping the imagination free from inhibitions.” (Jones & Thornley, 1963)

It is important to realise that the 1960s and especially this conference marks the definition of a typical task of the designer that we still recognise today, namely the idea of the designer as problem-solver, that first analyses the problem and then synthesises a solution. In the 1960s there was a very apparent need to revise the idea of the designer so he could deal with the highly industrialised and complex ways of production, which involve more and more automated systems not only in the process of production but within the products themselves as well. Also other product demands started to emerge like, user experience, marketing, cost-efficiency, ergonomics, etc. The opening address of the first conference on design methods by D.G. Christopherson illustrates this: “Perhaps it is worth while to take a minute or two to refer to what administrators are apt to call the supply situation for engineering designers. The traditional source has been from people who were trained on the drawing board as draughtsmen. It is common ground among almost everybody that this source is proving increasingly inadequate to meet present-day needs (...) technical progress has meant that the designer needs a much better education in fundamentals than was formerly necessary; it is much more difficult for him to get by on that combination of flair and rule of thumb which has been characteristic of even very good designers in the past.” (Jones & Thornley, 1963) In his address Christopherson explains the need for a new university degree course for design and unfolds an outline for what elements should be present in such a curriculum. What becomes clear is that trusting merely on ‘intuition’ is not enough anymore, and that a more systematised and rational way of dealing with design problems is needed in addition to the creative faculty of the mind. At the conference Jones unfolds his *Method of Systematic Design*, in which he says: “The following notes are an attempt to integrate all such developments (‘computers, automatic controls and systems’ ed.) that have come to the writer’s (J.C.Jones ed.) notice into a unified system of design. It is aimed particularly at the area that lies between traditional methods, based on intuition and experience, on the one hand, and rigorous mathematical or logical treatment on the other.” (Jones & Thornley, 1963)

The characteristics of *intuition* and *experience* are described as traditional methods and are given a place within the systematic method but are hardly defined themselves (very similar to how Turing worked around defining what intelligence itself could be with his Turing Test). Jones: “Little is known of what goes on in the mind during creative thinking, but it is clear that the power of imagination which any person can apply to the solving of a design problem is dependent on two external factors:

1. A clear statement of the problem.
2. A free atmosphere in which any idea, however crude or naive, can be expressed at any time without regard to its practicability.”

(Jones & Thornley, 1963)

The challenge according to Jones is in constructing a system which can streamline the process and makes use of the creative faculty in a efficient way within this process.

Jones explains: “The method is primarily a means of resolving a conflict that exists between logical analysis and creative thought.”(Jones & Thornley, 1963) The conflict which Jones describes takes as a premise that reason and intuition are each others antagonists, that the mind is not able to do good analysis when creativity comes in, and vice versa. Creative thought can only thrive if it is set free, as in a session of non-judgemental free association dubbed brainstorming. Apparently good logic needs rigor, creativity needs freedom. Giving each their own space to operate properly is what Jones’ Method is aimed at: “Existing methods depend largely on keeping logic and imagination, problem and solution, apart only by an effort of will, and their failures can largely be ascribed to the the difficulty of keeping both these processes going separately in the mind of one person. Systematic Design is primarily a means of keeping logic and imagination separate by external rather than internal means.”(Jones & Thornley, 1963) And this is what the method is, a handbook, defining separate phases of reason and creativity in the process of design.

Where Banham registers the opportunities as well as the dangers of a ‘Machine Age enthusiasm,’ Christopher Alexander also observes a historical development. The history of ‘design losing its innocence,’ firstly a in a *mechanical* sense and then as an *intellectual* loss of innocence, both caused by the machine, first as instrument and later as a metaphor for thought. In Alexander’s words one can also taste serious antagonism against the idea of the designer as artist.

“There has already been a loss of innocence in the recent history of design; the discovery of machine tools to replace hand craftsmen. A century ago William Morris, the first man to see that the machines were being misused, also retreated from the loss of innocence. Instead of accepting the machine and trying to understand its implications for design, he went back to making exquisite handmade goods. It was not until Gropius started his Bauhaus that designers came to terms with the machine and the loss of innocence which it entailed. Now we are at a second watershed. This time the loss of innocence is intellectual rather than mechanical. Again there are people who are trying to pretend that it has not taken place. Enormous resistance to the idea of systematic processes of design is coming from people who recognise correctly the importance of intuition, but then make a fetish of it which excludes the possibility of asking reasonable questions.(...)

The modern designer relies more and more on his position as an artist, on catchwords, personal idiom, and intuition for all these relieve him of some of the burden of decision, and make his cognitive problems manageable. Driven on his own resource, unable to cope with the complicated information he is supposed to organize, he hides his incompetence in a frenzy of artistic individuality. As his capacity to invent clearly conceived, well-fitting forms is exhausted further, the emphasis on intuition and individuality only grows wilder.”

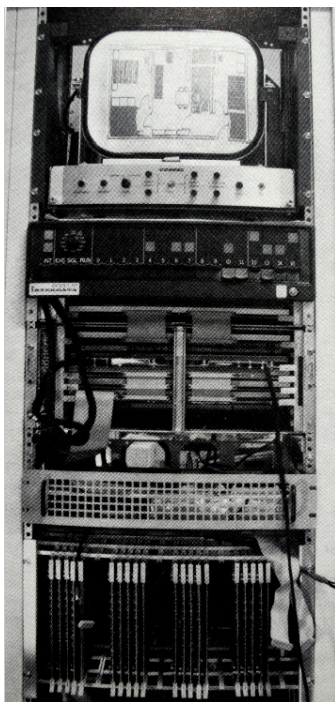
(Alexander, 1964)

The promise science and technology in the 1960s held for the future was so great that practically everything seemed possible, but the 60s also were a very turbulent time in which a new generation started to question the establishment and its conservative values. The new generation protested against the war in Vietnam, lent its strength to the civil rights movement, unleashed a sexual liberation and protested against the nuclear bomb. In the late 60s students were occupying university campuses and faculties all over the world demanding change. This was the awaking

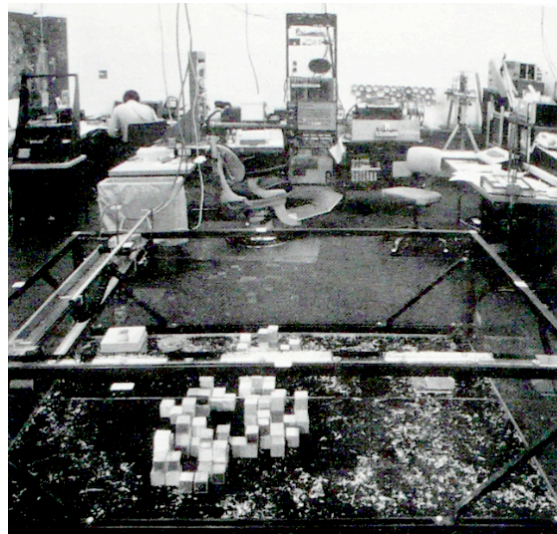
of a generation with liberal ideals, revolting against the conservative morality of the status quo. Also in architecture and design this was the case, the dominant conception of the architect as artist and auteur was put in question. The development of new methods for architectural design was also seen as a vehicle to fight the establishment within the architectural discipline. Amongst other things this is also where the computer plays a prominent role. In the 60s the computer was mostly present at research facilities of the government and military (ARPA, later DARPA) or corporations (RAND), but also at research facilities of universities. Still far removed from the mainstream the computer was still a profoundly experimental machine, although it held great promises it was still roughly two decades away that the first computers would enter the domestic domain. Firstly the universities population got access to the computer, and started experimenting with them. Consequently some of the ideals of that generation where fused into the computer (the ideals of empowering people and unconditionally sharing information have led to personal computing and the internet (Markoff, 2005).

1.1.3 The Architecture Machine

Machines substituting designers



(a) One of the 'architecture machines'



(b) The *Architecture Machine Group*'s lab at MIT

One of the best illustrations of early experimentation with computers in design is the Architecture Machine Group founded by Nicholas Negroponte at MIT' School for Architecture and Planning in 1968 (AMG later evolved into MIT Media Lab, which still exists). AMG was not directly after something we today would call CAD (Computer Aided Design), their idea about the computer in the design process was very different, as Negroponte states: "Around 1968 I

adopted the position that, if computers were to aid the evolution of architecture, they would have to be a class of machines that (we could generally agree) exhibited intelligent behavior. I took a stance that computer aided architecture without machine intelligence would be injurious because the machine would not understand what it was aiding.” (Negroponte, 1975) Negroponte’s idea of the role that the machine could play in design was not very specific, the AMG was mainly a group that engaged a wide variety of experiment inspired by utopian leftist ideals. For instance the machine was not to be a servant of the architect, but an equal. Not as a tool or instrument at service to the architect, but “rather of two associates that have a potential and a desire for self-improvement.” (Negroponte, 1970)

Ironically, the computer sciences, generally associated with elite and oppressive authorities (the most powerful computers were in service of the military, involved in calculation for the nuclear threats of the Cold War ed.), can provide to everyone a quality of architecture most closely approximated in indigenous architecture (architecture without architects). (...) I am interested in the rather singular goal of making the built environment responsive to me and to you, individually, a right I consider as important as the right to good education.” (Negroponte, 1975) With the references to ‘indigenous architecture,’ which is also Alexander’s main source of inspiration for his ‘design method’ and Rudofsky’s *Architecture without Architects* (1964), Negroponte is sketching an high-tech idyll, where technology enables the user to take control once again over their living environments without the need for architects. In the introduction of *Soft Architecture Machines*, Negroponte explicitly sates the desire to remove the architect out of the equation of producing architecture. “The reader will recognise in the following chapters an underlying theme that is antiarchitect. This is not to be confused with an antiarchitecture bias. (...) The general assumption is that in most cases the architect is an unnecessary and cumbersome (and even detrimental) middleman between individual, constantly changing needs and the continuous incorporation of these needs into the built environment. The architect’s primary functions, I propose, will be served well and served best by computers. In this sense the book is about a new kind of architecture without architects (and even without surrogate architects).” (Negroponte, 1975)

1.1.4 Design as Science of the Artificial

The reinvention of the design process thus ranges from the conception of more systematic methods for designing, in which intuition and creativity have a place next to rigour and logic, to the idea of design as merely the technical application of scientific knowledge. Herbert Simon is the protagonist that brings all these perspectives together, as one of the pioneers in AI and in writing the book *The Sciences of the Artificial* (Simon, 1969), which became the definitive text of the rational and systematic rendering of the design process that defined the design activity as a teachable *procedure* or *method* rather than a interactive and open *process* that should be mainly acquired through experience. According to Simon design essentially should be understood as a form of problem solving and one could define systematic and rational procedures of problem solving separate of the specific domains in which one was working. In other words a method of general problem solving. Within this rational problem solving approach the designer is seen as an information processor, very much like the role of the CPU in a computer system. Simon described problem solving as: “(...) the search for a solution through a vast maze of possibilities (within the problem space) (...) Successful problem solving involves searching the maze selectively and reducing it to manageable solutions” (Simon, 1969)

Kees Dorst gives us a concise breakdown of Simon’s theoretical framework of design as a

science. Dorst describes how Simon views designers, design tasks, design processes and design knowledge.

- Designers are basically information processors, they are seen as “as ‘goal-seeking information processing systems’, operating in an objective and knowable reality” (Dorst, 1997).
- The design task is to navigate through an ill defined, unstructured problem space with the goal to arrive at the most ‘satisficing’(as Simon calls it) solution. “Ill-structured problems are to be tackled in an ‘immediate problem space’. This is a part of the total problem space which is deemed too large, ill-structured and ill-defined to be described. The immediate problem space is addressed and put together by an (unspecified) ‘noticing and evoking mechanism’. The basic ‘design’ problem-solving process would be the same as in other kinds of problem solving” (Dorst, 1997).
- The Design process is a rational search process. Simon states that “design problems are (to be) hierarchically organised, and the way to design a complex structure is to discover viable ways of decomposing it into subproblems, solving these and combining them to arrive at a new overall solution” (Dorst, 1997).
- Design knowledge consists mainly of knowledge of procedures and ‘scientific’ laws. Simon lists the kind of knowledge which he thinks are essential for the education of designers: utility theory, statistical decision theory, algorithms for choosing optimal alternatives, algorithms and heuristics for choosing satisfactory alternatives, imperative and declarative logic, heuristic search, allocation of resources for search, hierarchic systems, representation of design problems.

What is important to notice here is that all the knowledge of design is knowledge of process, or more accurately, of procedures and not knowledge of product, or design artefacts. This fits the scientific approach which wants to be as objective as possible and thus excludes the entire cultural component of design. With merely knowledge of process, designers do become mere information processors and the factor of creativity or intuition stays unspecified, only qualified as a ‘noticing and evoking mechanism’, a sort of ‘random-number generator’ within this computer inspired model of design thinking (or in Jones’ model: a session of free-association, called ‘brainstorm’).

1.2 The Machine Rationale Breaks Down

Why rational and systematic methods don’t work with solving ill-defined problems

Herbert Simon’s *Sciences of The Artificial* was not only aimed at designers, Simon’s theory proposed a general problem solving framework for all disciplines that were engaged in making, managing, designing and planning the artificial. In other words any discipline engaged in actively making or manipulating our physical world. From the early 1960s on also in other disciplines than design the introduction of science based rational and systematic methods played a paramount role in the modern professionalisation of these disciplines. The *Sciences of the Artificial* synthesised this broad movement over all these diverse disciplines into a universal theory of general problem solving valid for all the disciplines that were engaged with the domain of the *artificial*.

In the same year Simon's book was published (1969) the first problems with this doctrine were showing. On December 1969 in Boston, Horst Rittel (Professor of the Science of Design) and Melvin Webber (Professor of City Planning, both at Berkeley) presented a paper at a panel on policy sciences, titled *Dilemmas in a General Theory of Planning*. Rittel and Webber registered some serious problems with the current rational and systematic methods professionals were using in their practices. They were not the only ones that saw a problem, also with the general public there was a growing discontent with *the professionals*. "In courts, the streets, and the political campaigns, we've been hearing ever-louder public protests against professions' diagnoses of the clients' problems, against professionally designed governmental programs, against professionally certified standards for public services" (Rittel & Webber, 1973). Although the professionals played a very important role in solving the problems of modern society and cities in the first half of the 20th century "The streets have been paved, and roads now connect all places; houses shelter virtually everyone; the dread diseases are virtually gone; clean water is piped into nearly every building; sanitary sewers carry wastes from them; schools and hospitals serve virtually every district; and so on." (Rittel & Webber, 1973) Rittel and Webber explain that these problems were comparatively simple to the problems society now faces and that we cannot address these problems anymore with existing rational systematic methods. "The professionalized cognitive and occupational styles that were refined in the first half of this of this century, based in Newtonian mechanistic physics, are not readily adapted to contemporary conceptions of interacting open systems" (Rittel & Webber, 1973) In open systems, cause and effect become practically untraceable, problems can actually be symptoms of yet another still invisible problem. Trying to grasp a problem in a definition or model becomes an impossible task in this way. Rittel and Webber "suggest that the social professions were misled somewhere along the line into assuming they could be applied scientist - that they could solve problems in the ways scientists can solve their sorts of problems. The error has been a serious one." (Rittel & Webber, 1973) Like in the social professions this deception is also the case for the designer, more or less depending on their trade. An industrial or engineering designer will have more use for scientific methods for dealing with certain problems than an urbanist or architect would. Rittel and Webber don't propose any alternative methods, but they analyse the differences in the kinds of problems the professions deal with and make a distinction between the 'tame' problems scientists and engineers deal with and the 'wicked problems' that one is confronted with in the planning, managing and design of the artificial. Tame problems are for example like "a problem of mathematics, such as solving an equation; or the task of an organic chemist in analyzing the structure of some unknown compound; or that of the chessplayer attempting to accomplish checkmate in five moves. For each the mission is clear. It is clear, in turn, whether or not the problems have been solved." (Rittel & Webber, 1973) Wicked problems on the other hand are "ill-defined; and they rely upon elusive political judgement for resolution. (Not 'solution.' Social problems are never solved. At best they are only re-solved - over and over again.)" (Rittel & Webber, 1973) This ill-defined characteristic of wicked problems results in that there is no definitive formulation of a problem, a problem doesn't end when its 'solved' and every problem is essentially unique "there always might be an additional distinguishing property that is of overriding importance." (Rittel & Webber, 1973) The point Rittel and Webber make is that a scientific informed professionalism is no the right one for dealing with wicked problems, rather an professionalism that should be informed by an epistemology that acknowledges the specific nature of wicked problems, since scientific methods are not able to tame these.

1.2.1 Design Methods in Architecture

A reserved welcome of design methods to the architectural discipline

With their paper, Rittel and Webber surface some problems with what Dorst calls the ‘rational problem solving’ paradigm. From the start of the design methods movement and their championing of systematic methods there also has been some reserve and scepticism. In December 1967 the Symposium on Design Methods in Architecture was organised at the Portsmouth School of Architecture (U.K). It was the first event on Design Methods concerning specifically the architectural design discipline. It was organised by Anthony Ward and Geoffrey Broadbent. Ward was interested in finding out in what way design methods could be the basis of a new approach to architectural education at the school. The symposium functioned to gather “unrelated factions” of the field of Design Method together, a field that “seemed too broad and uncoordinated”. Although the hosts of the conference see a potential for the use of systematic design methods: “We felt, however, that although design in architecture has a great deal to learn from this approach -and has a lot to offer to it- it is also different in kind from many other kinds of design” (Broadbent & Ward, 1969). In the foreword to the proceedings Geoffrey Broadbent writes: “We are not ‘committed’ to design method, in the sense that individuals are in certain other schools. Design method has, or has had, a particular connotation. It means, or has meant, the translation of techniques from Operational Research (OR) into design often to detriment of what the designer was actually trying to do.” (Broadbent & Ward, 1969)

So although Ward and Broadbent see some potential they also see some problems in an overly systematic approach, this also shows in the selection of speakers invited at the conference that represented different polarities within the discourse. “There were Subjective-Objective, Abstract-Real, Value-Fact, Process-Product, and Determinist-Existential polarities which were each discussed at the levels both of philosophy and application.” (Broadbent & Ward, 1969) Broadbent concludes his summary and reflections on the conference with a remark concerning the design process which still holds today. “It is likely that the new design methods will look remarkably like what the designer thinks he does already, but there will be a difference. They will draw on all the techniques available from OR (operation research ed.), System Analysis, Computing and the New Maths. But they will not be dominated by these techniques. The process itself will determine which techniques might seem to be relevant.” (Broadbent & Ward, 1969)

1.2.2 Second thoughts

The Design Methods protagonists distance themselves from the movement and AI can't live up to its bold promises

From the 1970s on the design methods movement starts to experience a backlash. The convictions that design should be turned into a science was being met with significant resistance. Some of the frontrunners in the field distanced themselves from the design methods field. In 1971 Christopher Alexander dismisses the whole concept of design methods in the preface of the second edition of *Notes on the Synthesis of Form*: “since this book was published (1964 ed.) a whole academic field has grown up around the idea of ‘design methods’ and I have been hailed as one of the leading exponents of these so-called design methods. I am very sorry this has happened, and want to state, publicly, that I reject the whole idea of design methods as a subject of study” (Alexander, 1971) Beside Alexander also others reacted against the mission of rationalising and objectifying design into a science of sorts. Even one of the founding father of the design methods movement John Christopher Jones wrote an article in 1977 titled *How My Thoughts About Design Methods Have Changed over the years* in which he wrote: “In the 1970s I reacted against design methods. I dislike the machine language, the behaviorism, the continual attempt to fix the whole of life into a logical framework” (Jones, 1977) After the mea culpas

of some of the once leading protagonists of the design methods movement, the movement lost momentum, although they found some application in the engineering disciplines, in architecture they were not able to find solid ground.

Also the Artificial Intelligent field was experiencing set backs in the 70s because they could not live up to there bold claims. In 1965 Simon claimed that “Machines will be capable, within twenty years, of doing any work a man can do”(Crevier, 1993) All AI research was state funded and the researchers were free to research whatever they wanted in the 1960s, there were no objectives to be met. This became a problem when the state agencies like DARPA started reviewing the results, and concluded that the usefulness of the developed AI technology for military purposes was extremely limited, and that there was limited prospect of improvement in the near future. AI researcher Hans Moravec explained this as follows:”Many researchers were caught up in a web of increasing exaggeration. Their initial promises to DARPA had been much too optimistic. Of course, what they delivered stopped considerably short of that. They felt they couldn’t in their next proposal promise less than in the first one, so they promised more.(Crevier, 1993) The collapse of funding from the early seventies till the early 80s became known as an AI winter and there were another ones in the late 80s and early 90s.

1.3 Human After All

“The professional’s job was once seen as solving an assortment of problems that appeared to be definable, understandable and consensual. He was hired to eliminate those conditions that predominant opinion judged undesirable.” (Rittel & Webber, 1973) “But although we are wholly dependent on them, there are increasing signs of a crisis in confidence in the professions.” (Schön, 1983)

The problems in the practices of professionals across disciplines have developed in a decade from Rittel and Webber’s ‘Dilemmas’ to ‘The Crisis of Confidence’ Schön writes about. Where Rittel and Webber only observe and analyse the problem, Schön comes with an alternative theoretical framework that displaces the positivist theories of ‘rational problem solving’. Schon sees the problem largely in the kind of epistemologies that are propagated within the educational institutions that fit academia, but do not fit the reality of practice. In the preface to his 1983 book *The Reflective Practitioner* Schön writes “I have become convinced that universities are not devoted to the production and distribution of fundamental knowledge in general. They are institutions committed, for the most part to a *particular* epistemology, a view of knowledge that fosters selective inattention to practical competence and professional artistry”(Schön, 1983) Because the epistemology propagated in the universities is mainly based on positivism, and positivism as demonstrated by Rittel and Webber is not necessarily the most fitting framework in the day-to-day practice of professionals. Thus Schön is convinced that “We are in need of inquiry into the epistemology of practice. What is the kind of knowing in which competent practitioners engage? How is professional knowing like and unlike the kinds of knowledge presented in academic textbooks, scientific papers, and learned journals? In what sense, if any, is there intellectual rigor in professional practice?”(Schön, 1983)

How to deal with ill-defined or so-called wicked problems is articulated in Donald Schön’s theory of ‘reflective practice’ that sought “an epistemology of practice implicit in the artistic, intuitive processes which some practitioners do bring to situations of uncertainty, instability,

uniqueness, and value conflict,” (Schön, 1983) and as Cross comments: “Schön appeared to be more prepared than his positivist predecessors to put trust in the abilities displayed by competent practitioners and to try to explicate those competencies rather than to supplant them” (Cross, 2006) Schön radically breaks in a very important aspect with the problem-solving paradigm as developed in the design methods and artificial intelligence field, and with Herbert Simon, its main protagonist. Simons endeavor was not so much explicating the modes of thinking that were involved in the designing process, but rather replacing the thinking of the designer by a new science inspired model to the point that it resulted in an algorithm with which not only a designer but eventually a machine could be programmed. Besides the believe in science and technology Simons theories also show an implicit mistrust towards the professional designer to solve complex problems. As illustrated earlier by Negroponte’s rhetoric. Schön on the other hand puts his trust and belief in the skills of the professional him/herself. Around this notion he builds his own theoretical framework in which he describes the designing process as a reflective conversation with the situation, in which he acknowledges the uniqueness and ill-definedness of the problems one is confronted with when designing. Schön puts the professional (designer) central in the rendering of the processes of thinking.

What needs to be understood is how critical it was and still is, to acknowledge the value of experience and knowledge of professionals, and to trust how they practice although most of the time practitioners -strictly taken- cannot account for most of the actions they undertake. Strictly taken in this sense means comparing for instance the process of the designer to that of a scientist. Although the scientist is also engaged in creative activities, such as generating theory, or a hypothesis, the actual experiments are determined by method, and for a theory to hold there is an solid argument needed, usually developed *a posteriori*. If you would measure how argumentation, choices and validation are done in both fields. Science is involved in elaborate argumentation before conclusions are drawn. Science is strict, but design usually has a hard time defending its process to the rigorous rules of science. To counter the paradigm of technical rationality in the professions, and for the professional practitioners to regain confidence in their own competencies Schön’s theory was able to position their way of practicing and giving it its own epistemology that could explain how practice involved different processes than those in research. This epistemological framework opened a common ground on which practitioners could distinguish themselves from the processes of science.

1.3.1 Reflection-in-Action

At the core of Schön’s theory is what he calls “a reflective conversation with a unique and uncertain situation” (Schön, 1983) The situation being a ‘problem’ that for instance, the architect, encounters in his/her design process. The point of reflection-in-action is that the actions and observation of the consequences of those action are deeply intertwined. “The process spirals through stages of appreciation, action, and reappreciation. The unique and uncertain situation comes to be understood through the attempt to change it, and changed through the attempt to understand it.” (Schön, 1983) This is what Schön refers to with the term ‘reflective conversation’. Problem and solution are co-evolving, through testing solutions the problem gets defined, which again invites new solutions to be tried out.

The engagement with a problem starts by choosing a context to deal with it. Framing or reframing the problem situation in a framework with which the practitioners feels confident of finding a solution. “The evaluation of the frame experiment is grounded in the practitioner’s

appreciative system. Through the unintended effects of action, the situation talks back. The practitioner, through reflection on this back-talk, may find new meanings in the situation which lead him to a new reframing. Thus he judges a problem-setting by the quality and direction of the reflective conversation to which it leads. This judgement rests, at least in part, on his perception of potentials for coherence and congruence which he can realize through his further inquiry.” (Schön, 1983) How does a practitioner know what frame to impose on an encountered situation? Schön’s answer is that past experience is brought in to bear on a unique situation: “The practitioner has built up a repertoire of examples, images, understanding, and actions. (...) A practitioners repertoire includes the whole of his experience insofar as it is accessible to him for understanding and action. When a practitioner makes sense of a situation he perceives to be unique, he sees it as something already present in his repertoire. To see this as that one is not to subsume the first under a familiar category or rule. It is, rather, to see the unfamiliar, unique situation as both similar and different from the familiar one, without at first being able to say similar or different with respect to what. (...) Seeing this situation as that one, one may also do in this situation as in that one. (...) It is our capacity to see unfamiliar situations as familiar ones, and to do in the former as we have done in the latter, that enables us to bring our past experiences to bear on the unique case. It is our capacity to see-as and do-as that allows us to have a feel for problems that do not fit existing rules.” (Schön, 1983)

For an epistemological framework for practice we still need to be more accurate about how judgments are made. Here the methodology of scientific research can be compared to that of reflection in action, because both share a similar activity; experimenting. “Reflection-in-action is a kind of experimenting. Practice situations are notoriously resistant to controlled experiment. How does the practitioner escape or compensate for the practical limits to controlled experiment? In what sense, if any, is there rigor in on-the-spot experiment?” (Schön, 1983) . Scientific research is involved in hypothesis testing through controlled experiment. “The experimenter is expected to adhere to norms of control, objectivity, and distance. By controlling the experimental process, he is to achieve objectivity, seeing to it that other inquirers who employ the same methods will achieve the same results.” (Schön, 1983) For professional practice these conditions are very practically impossible. “The practitioner is usually unable to shield his experiments from the effects of confounding changes in the environment. The practice situation often changes rapidly, and may change out from under the experiment. Variables are often locked into one another, so that the inquirer cannot separate them. The practice situation is often uncertain, in the sense that one doesn’t know what the variables are.” (Schön, 1983) As Schön shows, the circumstances of practice are very different than those of research. Although practice as well as research involves experimenting, the nature of the experiments are of completely different orders. Schön explains that in practice several kinds of experimenting are mixed up together.

“In the most generic sense, to experiment is to act in order to see what the action leads to. The most fundamental experimental question is: “What if?” (Schön, 1983)

Exploratory experiment

“When action is undertaken only to see what follows, without accompanying predictions or expectations, I shall call it exploratory experiment. This is much of what an infant does when he explores the world around him, what an artist does when he juxtaposes colors to see what effect they make, and what a newcomer does when he wanders around a strange neighborhood. (...) Exploratory experiment is the probing, playful activity by which we get a feel for things. It succeeds when it leads to the discovery of something there. ” (Schön, 1983)

Move-testing experiments

An action in order to produce an intended change. A move-testing experiment is “Any deliberate action with an end in mind” (Schön, 1983), consequently the move can be affirmed or negated if anything intended or unintended results from the move. The interesting element in move-testing is that that moves can produce effects beyond the intended, “One can get very good things without intending them, and very bad things may accompany the achievement of intended results.” (Schön, 1983) This ‘going beyond the intended’ results in the a logic that is not simply about affirming actions taken, its not about do you get what you intend, but, do you like what you get from the action, taken the consequences as a whole?

Hypothesis testing

Discriminating amongst competing hypothesis is also part of the experimenting in practice. The hypothesis tested are “implicit in the pattern of one’s moves” (Schön, 1983) and confirmation or disconfirmation follows from success or failure to get the consequences predicted in the hypothesis. This essentially follows the same logic as research, but there are important differences in the context in which practice works that set hypothesis testing in practice apart from that in research. The difference lies in “the relationship between changing things and understanding them.” (Schön, 1983)

“The practitioner has an interest in transforming the situation from what it is to something he likes better. He also has an interest in understanding the situation, but it is in the service of his interest in change. When the practitioner reflects-in-action in a case he perceives as unique, paying attention to phenomena and surfacing his intuitive understanding of them, his experimenting is at once exploratory, move testing, and hypothesis testing. The three functions are fulfilled by the very same actions. And from this fact follows the distinctive character of experimenting in practice.” (Schön, 1983) The engagement with the situation is not one of distance and objectivity but “the practitioner’s hypothesis testing consists of moves that change the phenomena to make the hypothesis fit.” (Schön, 1983) From the efforts of making the hypothesis fit the situation responds, it ‘talks back’. This is the reflective conversation Schön writes about. “The inquirer’s relation to this situation is *transactional*. He shapes the situation, but in conversation with it, so that his own models and appreciations are also shaped by the situation. The phenomena that he seeks to understand are partly of his own making; he is in the situation that he seeks to understand.” (Schön, 1983)

In Schön’s epistemology of reflection-in-action, knowledge and action are deeply intertwined. Instead of the problem being formulated as a question and the solution as the answer, the problem is a situation with which you enter into a conversation. Thinking in Schön’s model is the equivalent of action. The practitioner thinks through actions, manipulations of the situation and observations of the situation. Thinking is deeply effects knowledge, which is the equivalent of experience. Experience is what determines how a practitioner frames the situation, and also the extend to which he can oversee and predict that certain actions will lead to certain results, although at the same time he has to remain open for appreciating unintended effects. Knowledge thus to a large extend determines how situation are understood and dealt with, and thus knowledge or experience heavily influences thinking.

1.3.2 The Chinese Room

Thus one can argue that knowledge and thinking are indivisible. This has some implications when we reflect on one of the foundational ideas of the rational problem solving paradigm, namely that in this model knowledge and thinking are separated, as can be seen in the computer's division of memory (i.e. knowledge) and CPU (i.e. thinking). The rational problem solving paradigm was also the foundational idea underlying Artificial Intelligence. Although the 'AI winter' confronted the field with set-backs in funding around 1974, in 1980 AI was confronted with intellectual critique that seriously questioned the foundational ideas of AI, and with it the Turing test as the measuring stick of intelligence. In 1980 J.R. Searle presents the 'Chinese Room' argument against computation as a model for the mind in the article *Minds, Brains, and Programs* (Searle, 1980). The Chinese Room is a thought experiment, it consists of a room with in it a computer or a human. As input the room gets a story in Chinese plus some questions about it in Chinese. The computer as well as the human produces perfect answers in perfect Chinese. The human in the room is English speaking and doesn't speak or recognise any of the Chinese characters, these are just squiggles to him, but the human has a giant rule-book, limitless amounts of paper, pencils and erasers. Following all the rules in the book he produces the output that is a certain ordering of Chinese characters on paper and passes this through a slot through which the paper leaves the room. The output from the room answers all the questions in perfect Chinese. The question is: "what the human does here, can we call this intelligence?" Like the human, the computer shares the same level of understanding of Chinese, both of them just carry out given rules mindlessly. The process in the room carried out by the human consists of the exact same operations as done by a computer running a program (the rule-book) namely; reading, writing

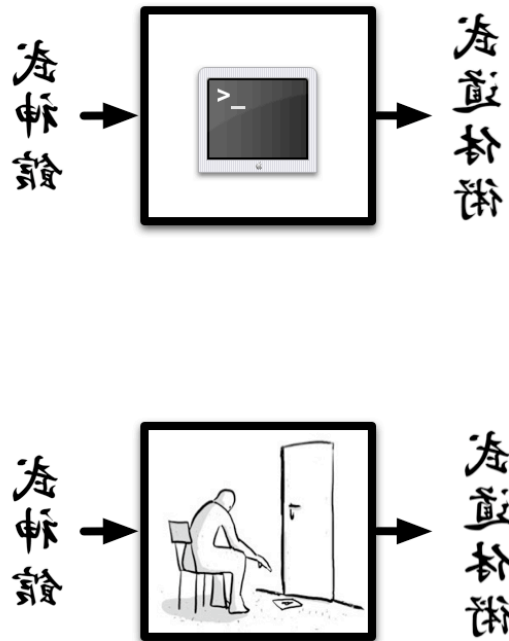


Figure 1.5: A representation of the Chinese Room thought experiment

and erasing. The Chinese Room experiment profoundly questions the judging of intelligence through behavior.

1.3.3 Intelligence as determined by prediction, not behaviour

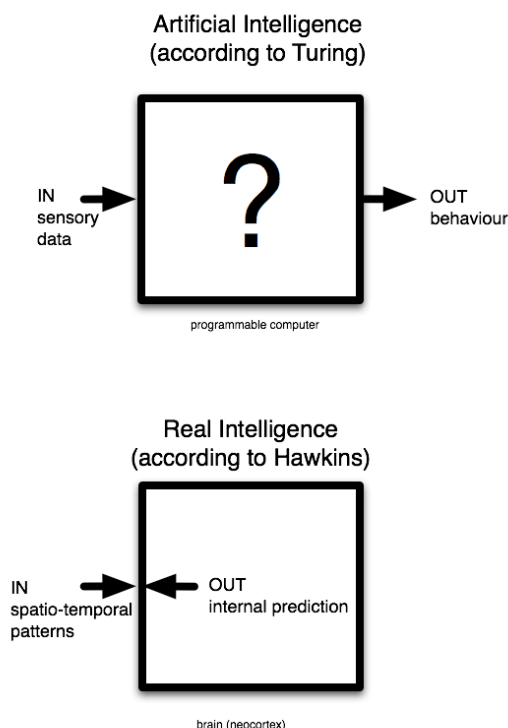


Figure 1.6: A representation of Turing's intelligence test

Recently a new theory for how intelligence would work was developed by Hawkins (2004), a computer architect turned neurologist. Because he believed you can only make an intelligent machine if we understand what intelligence itself actually is, and that this can only be discovered if we understand how the brain produces it. Hawkins' ideas are closest to the field called Neural Networks, although he is very critical about what the field has accomplished he builds on some of it's basic premises. The Neural Network field has for long a competitor of the AI field proper. AI was aiming to make intelligent machines by programming computers, where Neural Networks had another approach in the endeavour of finding intelligence. "Instead of programming computers, neural network researchers, also known as *connectionists*, were interested in learning what kind of behaviours could be exhibited by hooking a bunch of neurons together. Brains are made of neurons; therefor the brain is a neural network. That is a fact. The hope of connectionists was that the elusive properties would become clear by studying how neurons interact, and that some of the problems that were unsolvable with AI could be solved by replicating the correct connections between populations of neurons. A neural network is unlike a computer in that it has no CPU and doesn't store information in a centralised memory. The network's knowledge and

memories are distributed throughout its connectivity-just like real brains” (Hawkins & Blakeslee, 2004) While most Neural Network researcher were still explaining intelligence with the parameters of behaviour, a neural network does acknowledge the indivisibility of knowledge and thinking, since the knowledge (memory) is an integral part of how the system operates. The memories are distributed throughout the network and determine how connections are being made, so the memories change the functioning of the network determined on what they receive as input, or ‘learn’. Hawkins’ theory also acknowledges the indivisibility of knowledge and thinking but also steps away from judging intelligence by behaviour. Hawkins explains: “The brain is not a computer, supplying by rote an output for each input it receives. Instead, it is a memory system that stores experiences in a way that reflects the true structure of the world, remembering sequences of events and their nested relationships and making predictions based on those memories. It is a memory-prediction system that forms the basis of intelligence, perception, creativity, and even consciousness. Intelligence is the capacity of the brain to predict the future by analogy to the past.” (Hawkins & Blakeslee, 2004) In Hawkins’ theory memory is organised in such a way that it ‘reflects the true structure of the world’, and this memory is active, it is returned to its input through feedback, it is continuously matched against the real world, i.e. predicting. Through this continuous matching of memory and reality, things seem alike, we recognise things, thus we can draw analogies and make metaphors. The organisation and structure of knowledge in our heads results directly in how we think, what we think. Let’s make this theory more concrete with an anecdote. Hawkins calls this the altered door experiment:

“When you come home each day, you usually take a few seconds to go through your front door or whichever door you use. You reach out, turn the knob, walk in, and shut it behind you. It’s a firmly established habit, something you do all the time and pay little attention to. Suppose while you are out, I sneak over to your home and change something about your door. It could be anything. I could move the knob over by an inch, change a round knob into a thumb latch, or turn it from brass to chrome. I could change the door’s weight, substituting solid oak for a hollow door, or vice versa. I could make the hinges squeaky and stiff, or make them glide frictionlessly. I could widen or narrow the door and its frame. I could change its color, add a knocker where the peephole used to be, or add a window. I can imagine a thousand changes that could be made to your door, unbeknownst to you. When you come home that day and attempt to open the door, you will quickly detect that something is wrong. It might take a few seconds reflection to realize what is wrong, but you will notice the change very quickly. As your hand reaches for the moved knob, you will realize that it is not in the correct location. Or when you see the door’s new window, something will appear odd. Or if the door’s weight has been changed, you will push with the wrong amount of force and be surprised. The point is that you will notice any of a thousand changes in a very short period of time”

“There is only one way to interpret your reaction to the altered door: your brain makes low-level sensory predictions about what it expects to see, hear and feel at every given moment, and it does so in parallel. All regions of your neocortex are simultaneously trying to predict what their next experience will be. Visual areas make predictions about edges, shapes, object, locations, and motions. Auditory areas make predictions about tones, direction to source, and patterns of sound. Soma-sensory areas make predictions about touch, texture, contour, and temperature.”

“Prediction” means that the neurons involved in sensing your door become active in advance of actually receiving sensory input. When sensory input does arrive, it is compared with what was expected. As you approach the door, your fingers, when you

will feel the door, and at what angle your joints will be when you actually touch the door. As you start to push the door open, your cortex predicts how much resistance the door will offer and how it will sound. When your predictions are all met, you'll walk through the door without consciously knowing these predictions were verified. If your expectations about the door are violated, the error will cause you to take notice. Correct predictions result in understanding. The door is normal. Incorrect predictions result in confusion and prompt you to pay attention. The door is off center. The texture of the knob is wrong. We are making continuous low-level predictions in parallel across all our senses.

But that's not all. I am arguing a much stronger proposition. Prediction is not just one of the things your brain does. It is the primary function of the neocortex, and the foundation of intelligence. The cortex is an organ of prediction. If we want to understand what intelligence is, what creativity is, how our brain works, and how to build intelligent machines, we must understand the nature of these predictions and how the cortex makes them. Even behavior is best understood as a by-product of prediction."

(Hawkins & Blakeslee, 2004)

1.3.4 Analogy in action

Making predictions by analogy to the past is according to Hawkins the foundation of what intelligence is and thus also operative in the designing process. What is most important here is the part of the phrase by analogy to the past. The past is our accumulated memory, all our experiences gathered up till this very moment. The guiding principle in intelligence and thus in the thinking which is also operative in designing is 'analogy. Analogy is the concept that describes how our internal world of the mind relates to the external world outside our mind. In our experience analogy is a concept that is omnipresent in human culture and of fundamental importance for the development of knowledge. In literature analogy manifests itself as allegories, metaphors, similes, comparisons and parables, or in language in proverbs and idioms. Also in science and philosophy the analogy can be seen in the guises of correspondence, homology, homomorphism, iconicity, isomorphism, resemblance and similarity. If we look to the designing process, Schön gives a perfect illustration of how analogy is part of design practice. When we read Schön as he explains the process of reflection-in-action we can see how analogy, although he does not use the term itself- plays a central role in designing.

"What I want to propose is this: The practitioner has built up a repertoire of examples, images, understandings, and actions. Quists (a design teacher) repertoire ranges across the design domains. It includes sites he has seen, buildings he has known, design problems he has encountered, and solutions he has devised for them." (...) "When a practitioner makes sense of a situation he perceives to be unique, he sees it as something already present in his repertoire. To see this site as that one is not to subsume the first under a familiar category or rule. It is rather, to see the unfamiliar, unique situation as both similar to and different from the familiar one, without at first being able to say similar or different with respect to what. The familiar situation functions as a precedent, or a metaphor, or -in Thomas Kuhns phrase- an exemplar for the unfamiliar one. Kuhns description of the functioning of exemplars in scientific problem solving is apposite here: *Confronted with a problem, [one] seeks to see it as like one or more of the exemplary problems he has encountered before his*

basic criterion is a perception of similarity that is both logically and psychologically prior to any of the numerous criteria by which that same identification might have been made Under appropriate circumstances there is a means of processing data into similarity sets which does not depend on a prior answer to the question, similar with respect to what?

Seeing this situation as that one, one may also do in this situation as in that one. When a beginning physics student sees a pendulum problem as a familiar inclined plane problem, he can set up the new problem and solve it using procedures both similar to and different from those he has used before. Just as he sees the new problem as a variation on the old one, so his new problem-solving behavior is a variation on the old. Just as he is unable at first to articulate the relevant similarities and differences of the problems, so he is unable at first to articulate the similarities and differences of his problem-solving procedures. Indeed, the whole process of seeing-as and doing-as may proceed without conscious articulation.”

(Schön, 1983)

The repertoire is in this case the accumulated past experiences of the designer, or memory according to Hawkins. Whereas seeing-as and doing-as are ‘predictions by analogy’, the action is carried out in analogy with a memory so to say. Seeing-as is an analogy through reflection, observing a similarity and imagining it in the minds eye. Doing-as is an analogy by acting, doing similar things in situation one recognises as similar. Although there is a 20 year gap between their writings, the theories of Schön and Hawkins bring the worlds of Design Methodology and Artificial Intelligence once again together. Even though they come from different discourses, they both respond to positivist paradigm that underlayed the dominant theories of design and intelligence. It will be interesting to see in what way we can come to a higher resolution image of what reasoning in design looks like with the convergence of these two theories. Schön wrote his theory as a primer, a sketch for an epistemology of practice, Hawkins’ theory can help in filling in some more details into the sketch which Schön has prepared. With this we can come closer to an explanation of what reasoning in design, and specifically architectural design is.

Chapter 2

Thinking in Architectural Design as a Form of Reasoning

How can we understand the intuitive and creative processes of architectural design as a form of reasoning or logic? This is the guiding question of this chapter, contrary to the departure point of Design Methodology in the 1960s, where reason and intuition are understood as antagonists. The previous chapter introduces Schön, who explains the designers' 'artistry of practice' as a process with implicit rational characteristics, and Hawkins, who has developed a theory of intelligence which stands at the foundation of the creative capacity as much as it explains logic and reason. What the previous chapter shows is that knowledge and thinking are indivisible. There is no thinking process that is devoid of knowledge, the nature of the knowledge one absorbs directly influences the characteristics of thinking. The organisation of knowledge inside and outside the mind determines the structure of reasoning, it effects how thoughts can unfold and constitutes the playing field for creativity and intuition.

“... in speaking of logic, we do not need to be concerned with processes of inference at all. While it is true that a great deal of what is generally understood to be logic is concerned with deduction, logic in the widest sense, refers to something far more general. It is concerned with the form of abstract structures, and is involved the moment we make pictures of reality and then seek to manipulate these pictures so that we may look further into the reality itself. It is the business of logic to invent purely artificial structures of elements and relations.”

(Alexander, 1964)

This definition of logic opens up a much wider horizon than what we popularly understand as logic, which is associated with strict argumentations and mathematical precision is aimed at producing statements that are 'true'. If we seek to understand design activity as a form of reasoning it is evident that we need to step away from a type of reasoning that seeks an indisputable truth. Design can never defend its 'truth' with rock solid arguments that derive from indisputable premises because the situation design deals with is too complex. Problems are wicked or ill-defined, the 'solution' or end-product may be satisfactory but it is difficult to argue that a certain design is the optimum solution. Reasoning in design is not about producing true arguments, however, designers use arguments, and exchange them, when defending their design decisions and ideas to their clients, peers or team-members. What than, is reasoning in design about ? What is its objective? How does it work? And how do we learn it, use it, develop it?

Schön sketches a first outline for these questions, but as he says himself his theory is but a primer, and details have to be added. This is where Hawkins' intelligence theory can play its role in filling in the details in Schön's epistemological framework. While Hawkins isn't directly concerned with the same questions that Schön asks, he can help us in clarifying the concepts that Schön introduces like the nature of 'repertoire', the workings of 'bringing past experience to bear on a unique situation' and how the architect uses his 'appreciative system' in judging the experiments that are 'implicit in the moves' he or she makes. Something more is needed, where Schön has to present 'reflection-in-action' as a valid method in contrast to the methods of 'technical rationality,' requiring Schön to make a comparison of identical methods, which in a different way operate in their respective methods ('reflection-in-action' and 'technical rationality'), thus he has to explain the differences in how reflection in practice is rigorous, how hypothesis testing works, what an experiment is. This is why reasoning is introduced, reasoning creates a common ground between different methods and the paradigms they're built on. Where Schön develops a new meaning for known methodological concepts, his theory can be further elaborated through developing notions on how concepts of reasoning work differently within his theory and that of others.

Thus I see 'reasoning' as a level of detail I can add to the 'primer' Schön wrote. Hawkins is introduced to get a better understanding of the concepts Schön introduced ('repertoire' and 'appreciative system') which are very important in defining the nature of reasoning in design practice.

2.1 The Nature of Reasoning in Architectural Design

Reasoning is very much about what we believe to be true or what we feel to be true, in other words things have to make sense. In other words we need to be persuaded by what we encounter or what is presented to us. Sometimes it may require effort to understand something, other times it may make sense immediately. The designer needs to persuade a variety of audiences (clients, peers, the public) as he has convinced himself, he has developed a belief in his own design over the course of the design process. The design process is an activity that works towards letting the design make more and more sense. That arguments lock into each other, with the chosen framework and concept, and together form a consistent entity or what Schön calls, "a universe of one" (Schön, 1983).

The persuasive nature of reasoning in design is aimed at generating a plausible outcome, one that makes sense in a certain way, convincing both the designer and the audience. The application of reasoning in design is similar to the application of reason in rhetoric.

Rhetoric is equipped with the instruments of proving a point through correct logical reasoning (logos), but some other elements come into play as well such as the power of a speaker to present himself as credible (ethos) and the speaker's power to stir the emotions of his audience (pathos). The kind of reasoning in rhetoric, though similar to logic, has its own characteristics as well, which Aristotle explains in his treatise on Rhetoric. (Aristotle, 350BC)

2.1.1 Three Modes of Reasoning

Before we explain the nature of reasoning as used in rhetoric, we should make clear the basic concepts of reasoning, namely deduction and induction. Both modes of reasoning reach a conclusion, usually a truth, in different fashions. A conclusion that results from deductive reasoning is determined by the premises from which the deduction operates. These premises are accepted truths, and in the case of deduction have a general character. For the conclusion to be true the premises have to be true as well. Through these accepted *general* truths, deduction reaches a

specific conclusion. Through such accepted truths we can state for instance that; assuming Isaac newton's theory of gravity is true (general truth), that from observing the heavenly bodies, a certain heavenly body should have a certain mass, position and orbit (specific conclusion). The power of the process of deduction is in projecting the right assumptions on data observed in a certain context.

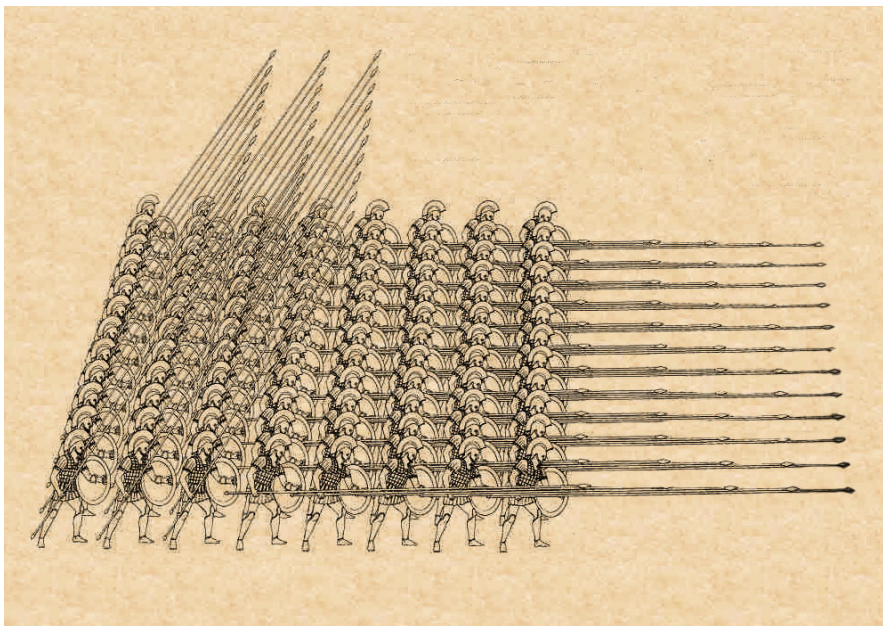


Figure 2.1: A Phalanx battle rout formation

The power of induction on the other hand is in constructing these generally accepted truths from which deduction operates. Induction works through constructing a notion that makes a fitting representation of what is observed in the real world. In this case specific observations lead to general conclusions. The power of this logic, is in bringing a series of observations together and connecting them to each other to 'see' how they imply a general truth. Rudolf Arnheim sketches beautifully how Aristotle describes induction:

"His (Aristotle ed.) curious example of the battle rout is significant enough (see Figure 2.1 for an example of a battle rout ed.). It describes induction as the restoration of an 'original formation,' that is, as a way of attaining access to a pre-existing entity, to which the individual cases relate as do the parts to a whole. It is true that Aristotle was the first thinker to recognize that substance is nowhere but in individual objects. He thereby furnished the basis for our knowledge that nothing exists beyond individual existences, However, the individual case was by no means abandoned to its particular uniqueness, from which only generalizing thought could redeem it. Immediately after describing the procedure of induction Aristotle writes the remarkable sentence:

When one of a number of logically indiscriminable particulars has made a stand, the earliest universal is present in the soul: for though the act of sense-perception is of the particular, its content is universal -is man, for example, not the man Callias.

In other words, there is no such thing as the perception of the individual object in the modern sense. “Perception as a faculty,” Aristotle says elsewhere, “is of ‘the such’ and not merely of ‘this somewhat,’ i.e., we always perceive, in the particulars, kinds of thing, general qualities, rather than uniqueness. Therefore, although under certain conditions events can be understood only when their repeated experience leads to generalization by induction, there are also instances in which one act of vision suffices to terminate our enquiry because we have “elicited the universal from seeing.” We see the reason of what we are trying to understand “at the same time in each instance and intuit that it must be so in all instances.” This is the wisdom of the universals in re, as it was to be called later, the universal given within the particular object itself - a wisdom which our own theorizing is struggling to recover in its concern with Wesensschau, i.e., the direct perception of essences.”

(Arnheim, 1969)

Here we have briefly summarised deduction and induction. As shown deduction takes an accepted truth and projects it on that what is perceived. Projecting this truth helps one to get a grip on the situation at hand. In the case of Newton’s theory of gravity it is functional in explaining the observed data. In the case of the architect it is useful to project an ‘assumed truth’ in order to frame and guide the design task at hand by for instance projecting a grid over the site, the grid imposes a certain logic on the site that in turn generates a guiding structure for the design activity. This projection on the situation will nevertheless lead to a unique outcome based on the particulars of the situation. One could say that deduction is concerned with the application of knowledge we already know, and induction is concerned with acquiring or abstracting new knowledge. Obviously we need both in our lives, and both modes of logic are mutual dependant, for the one applies the premises the other generates.

Since the middle of the 19th century logician and philosopher C.S. Peirce (1839-1914) elaborated on a third type of logical reasoning: abduction. Where deduction uses general assumptions to come to a specific conclusion, and induction gathers specific observations and extracts from that general conclusions, abduction is working the other way around. It starts at the conclusion, for which it tries to find possible explanations. So from the conclusion, hypotheses have to be generated to explain why the conclusion is as it is. Peirce claims that abduction is the only form of logic with which the truly novel can be discovered. Where deduction draws on pre-existing truths, and induction on sensory experience, abduction draws on both but adds conjecture to it. The notion of abduction evolved during Peirce’s life, and the notion was referred to with different terms, such as ‘hypothesis’ and ‘retroduction’ “In his very first papers concerning this mode of inference, that is, his Harvard Lectures in 1865, he also used the term ‘reasoning a posteriori’ in parallel with the term ‘hypothesis’.” (Paavola, 2006). Peirce developed the idea of abduction in different ways, at first syllogistically and later on it started to refer more to intuition, a guessing instinct, which he also called, ‘weak inference’. Peirce had defined a type of reasoning involved in discovery and the generation of new ideas. This has always been a problematic element in the philosophy of science. While the scientific method is a logically clear process, the method starts with posing a hypothesis, but where does this come from? Peirce was concerned with the question of how humans so often discovered such fertile hypotheses, when induction and deduction couldn’t explain it. “abduction is treated as a first stage of inquiry with which hypotheses are invented and provisionally adopted but because of its weakness these hypotheses must then be made clearer with deduction, and tested with induction.” (Paavola, 2006)

The concept of abduction is problematic as a category of reasoning next to deduction and induction. Deduction and induction are counterparts, the mirror image of each other. Both operate in a distinctly different fashion, whereas abduction is in many ways similar to induction; because it also works from an observation to generate the arguments that explain the observation. Also Peirce admitted he mixed up the two at a certain point in his career. (Paavola, 2006)

Some have hinted (March, 1976) that abduction could perhaps be the mode of reasoning associated with design. But my position is that this is problematic, and that abduction alone it is not enough for acquiring a deeper understanding of reasoning in design. Peirce claims that abduction is the only form of logic with which the truly novel can be discovered. Abduction is a form of theorising, an active effort to get a deeper insight into the reality we are confronted with every day. Because the world confronts us with endless phenomena, or ‘conclusions’, we don’t always understand. Such conclusions are the situations we observe and try to understand, so our mind tries to find the right arguments that support the ‘conclusion’ of reality we are confronted with. The speculation is based on everything we already know, and everything our sensory apparatus feeds to our brain. In this sense the description of abductive reasoning comes close to elements of Hawkins’ intelligence theory; the mind speculates (predicts) about the future in analogy to what it already knows (the past). To link Peirce’s abduction to Hawkins’ intelligence requires a certain reading of Peirce’s theory, and as Sami Paavola has documented, the interpretations of Peirce have been quite diverse (in science the common understanding of abduction usually is known as *Inference to the Best Explanation* but this one interpretation). Peirce has left some room for speculation within this concept he developed throughout his entire career

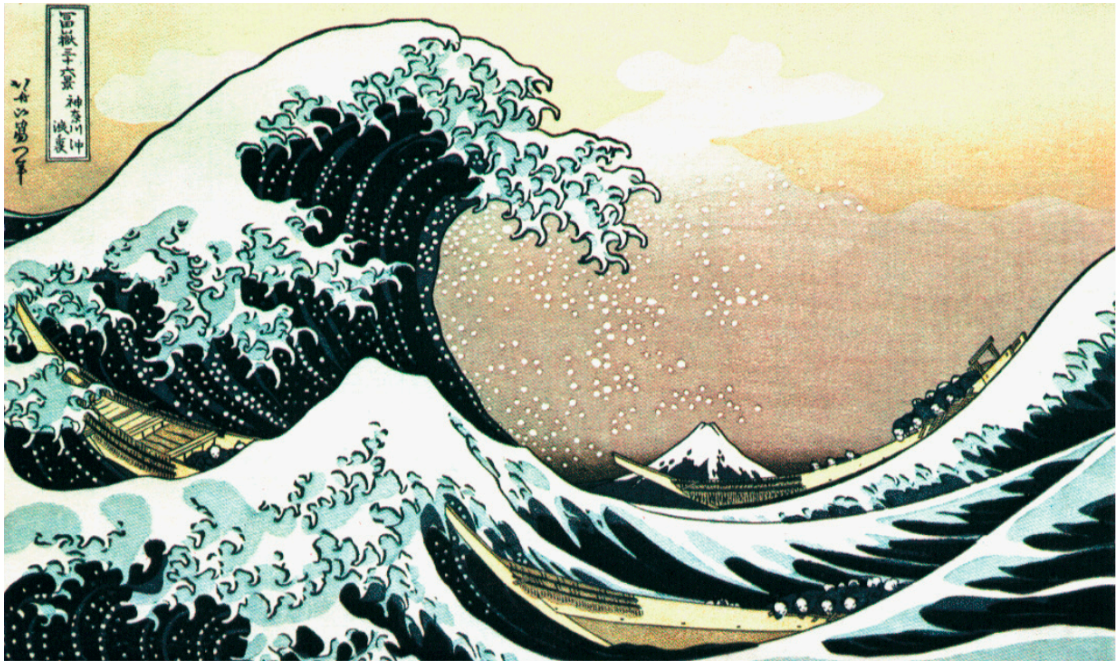
Later in this chapter we will see how induction, deduction and abduction can be understood in the framework of the design process.

2.1.2 Rhetoric Reasoning in Architectural Design

Why the rhetoric use of deduction and induction is in general a more fitting description of the reasoning in architectural design

Aristotle defines rhetoric as “the faculty of observing in any given case the available means of persuasion” (Aristotle, 350BC) on the topic of such means of persuasion he explains that part of the means are “such things as are not supplied by the speaker but are there at the outset - witnesses, evidence given under torture, written contracts, and so on.” (Aristotle, 350BC) and the other part “we can ourselves construct by means of the principles of rhetoric.” (Aristotle, 350BC) The rhetoric faculty consists of sharp observation of a situation and perceiving what can be useful in constructing an argument, and the invention of the argument itself, in what way to deliver it, communicate it. One can draw parallels from this description to how Schön explains how the practitioner deals with a situation; the architect has to construct an argument, the design of architectural form, which takes advantage of a set of perceived and carefully selected features found in the situation, things that are there from the outset.

There are two kinds of argument one can make in Rhetoric, one is the ‘Enthymeme’ which is the rhetorical version of deduction and the argument by ‘Example’ which is the rhetorical version of induction. The example has two varieties “one consisting on the mention of actual facts, the other in the invention of facts by the speaker” (Aristotle, 350BC) All examples consist of drawing analogies between real or invented situations and the situation in the point one wants to make. “all you require is the power of thinking out your analogy, a power developed by intellectual training” (Aristotle, 350BC)



(a) Katsushika Hokusai, The Great wave at Kanagawa (from a series of thirty-six views of Mount Fuji)



(b) Yokohama International Port Terminal designed by Alejandro Zaera-Polo's office FOA

Figure 2.2: The Hokusai Wave used as a rhetoric induction; example to support the design of the Port Terminal building. Suggesting that the Hokusai wave 'is like' the Port Terminal

An architectural illustration of this example, the rhetorical induction would be Alejandro Zaera-Polo's tale of the Hokusai Wave, which occurred to him when working on the Yokohama International Port Terminal (see Figure 2.2b).

"It started, actually, ten years ago in one of those episodes that radically change one's perception of reality. Faced with a full press conference in the Yokohama City Hall, circa February 1995, we had to explain what it was we were trying to do in our newly awarded Yokohama Competition project. Faithful to our doctrine, ne tuned through years of academic practice, we proceeded to explain the circulation diagrams, the geometric transformations, and the construction technologies that were involved in the project, hoping that the audience would have enough patience to wait for the emergence of the project. Halfway through the presentation, we started to notice the blank expression of the public in the room a clear indicator that the message was not coming across (this was to become a very common experience during our evolution. . .). After a few minutes of cold sweat, an image that was carefully edited from the project's discourse but still oating somewhere in the back of our minds came suddenly to our rescue. It was the Hokusai Wave, a drawing from a local painter that we had been toying with while we indulged in geometric manipulations and construction hypotheses during the design phase of the competition entry. In a sudden and risky burst of inspiration, we terminated the factual process narrative to conclude that what really inspired us was the image of Hokusai's Wave (see Figure 2.2a ed.). The room exploded in an exclamation of sincere relief: 'Aaaahhh. . . !' and we left the room, still sweating and grateful for that moment of lucidity, and with the clear realization that something wasn't quite working in our carefully crafted discourse."

(Zaera-Polo, 2005)

When Zaera-Polo explains that the design 'is like' the Hokusai Wave he strikes a chord with his audience. The example allows his audience to suddenly read the design in a for them familiar context. And Zeara-Polo discovers something that Aristotle also wrote about: "It is this simplicity that makes the uneducated more effective than the educated when addressing popular audiences – makes them, as the poets tell us, 'charm the crowd's ears more finely.' Educated men lay down broad general principles; uneducated men argue from common knowledge and draw obvious conclusions." (Aristotle, 350BC) Beside the persuasive use of the Hokusai Wave, the example was not completely invented, as they 'had been toying with it while they indulged in geometric manipulations and construction hypotheses during the design phase' so it was also part of the design process itself.

After the discovery of the 'Hokusai Wave principle' as useful in more ways than just 'toying' with it in the design process, Zaero-Polo explains that they more consciously started to work with this phenomena, which he later calls 'form with a double agenda':

"Paradoxically, this strategy, originally devised to respond to commercial demands, became the foundation of a series of commissions for local authorities, most of them in Spain. Short-circuiting our conventional arsenal of diagrams and constructive solutions with locally resonant iconographies became a very effective technique to territorialize our constructed foreignness and connect with local agents. Local iconographies became a perfect excuse to naturalize materials and geometries that would have been otherwise vulnerable to budget cuts or political uncertainty. Moreover, iconography helped us accelerate the identification of traits from our usually

hypertrophied site and program analysis in order to provide a formal argument for the projects. Iconographies did not precede the material investigation but rather emerged as viable guides from our immersion in each project's analysis. We would collect general material about local customs and iconographies and keep that information on the table while we did site analysis and programmatic diagrams. We knew that a project was structured when a formal correlation started resonating between them."

(Zaera-Polo, 2005)

The Enthymeme is as Aristotle calls it a rhetorical syllogism. A syllogism is a kind of logical argument in which one proposition (the conclusion) is inferred from two others (the premises), the syllogism lies at the core of deductive reasoning. The rhetorical syllogism the "The enthymeme must consist of few propositions, fewer often than those which make up the normal syllogism. For if any of these propositions is a familiar fact, there is no need even to mention it; the hearer adds it himself." (Aristotle, 350BC) Deductive reasoning in rhetoric is a performative form of reasoning, aimed at effect, and tailored to an audience. An architect will explain his project differently in a pitch to a client than he will to his peers in a conference. Depending on the audience one can leave out steps and propositions in the line of argument, since the concern is if the point gets made with a specific audience. But how do we determine what propositions or 'facts' to include in our line of argument. About this Aristotle says: "There are few facts of the 'necessary' type that can form the basis of rhetorical syllogisms. Most of the things about which we make decisions, and into which therefore we inquire, present us with alternative possibilities. For it is about our actions that we deliberate and inquire, and all our actions have a contingent character; hardly any of them are determined by necessity. Again, conclusions that state what is merely usual or possible must be drawn from premisses that do the same, just as 'necessary' conclusions must be drawn from 'necessary' premisses." (Aristotle, 350BC) Thus the facts that are at the architects' disposal are the site, the briefing and an assessment of the complete situation (politically, economically, etc) in which his design endeavour has to take place. From these facts he constructs arguments, why his design should be one way or the other. The propositions used to make an enthymeme, have a special character, for they are not necessarily true, but they are generally true, commonplace or accepted truths for a specific audience. These kinds of propositions are 'Maxims'. "It is a statement; not a particular fact, (...) but of a general kind; nor is it about any and every subject." (Aristotle, 350BC)

As an example:

"There is no man in all things prosperous,

and

There is no man among us all is free,

are maxims; but the latter, taken with what follows it, is an Enthymeme –

For all are slaves of money or of chance"

(Aristotle, 350BC)

An architectural illustration of the enthymeme is beautifully given by Joshua Prince-Ramus in a lecture in 2006 at *TED* (Prince-Ramus, 2006). Joshua Prince-Ramus worked as the U.S partner of O.M.A on the Seattle Central Library (and now has his own firm, REX). What follows is an edited transcription from the lecture where he lays down the argument for the design of the Seattle Central Library (SCL).

Joshua Prince-Ramus:

“I’m gonna build up the SCL before your eyes in five or six diagrams, and I truly mean this is the design process that you’ll see.”

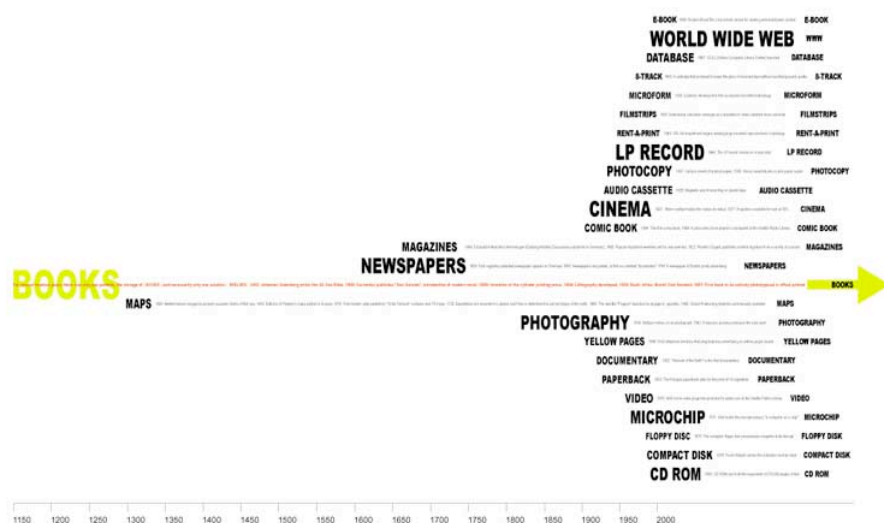


Figure 2.3: “Books have to share attention with other media of potent performance and attraction” (O.M.A, 1999)

“This diagram (see figure 2.3 ed.) was our position piece about the book, and our position was: ‘books are technology’, that is something people forget. It’s a form of technology that will have to share it’s dominance with any other form of truly potent technology or media.”

“The second premise, and this was something that was very difficult of convincing the librarians of at first, that libraries since the inception of the Carnegie library tradition in America, have a second responsibility and that is for social roles (see figure 2.4 ed.). (...) Something about which the librarians at first said: ‘this isn’t our mandate, our mandate is media and particularly the book’.”

From this transcription we can take the first maxim that: Books are a form of technology that will have to share it’s dominance with any other form of truly potent technology or media. The second maxim is that: Libraries have the responsibility to take on social roles.

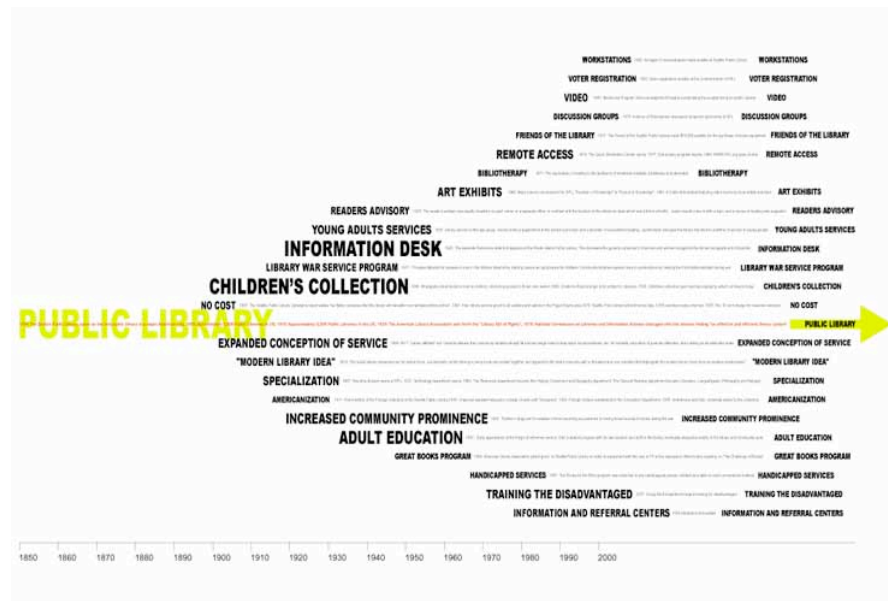
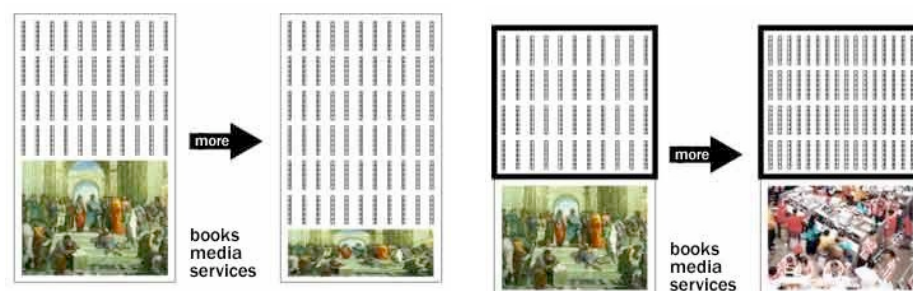


Figure 2.4: “The Library has been transformed from a space to read into a social center with multiple responsibilities”

(O.M.A, 1999)



(a) “Flexibility in recent libraries - San Francisco, Denver, Phoenix - has been conceived as the creation of floors on which almost any library activity can happen. Programs are not separated, rooms or individual spaces not given unique character. In practice, it means that the bookshelves define generous reading areas at the opening, then expand inexorably to encroach on public space. Ultimately, in this form of flexibility, the Library strangles its own attractions.”

(b) “A more plausible strategy divides the building into spatial compartments dedicated to and equipped for specific duties. Flexibility can exist within each section, but not at the expense of any of the other compartments... Change is possible by deliberately redefining use, rededicating compartments to new programs. (Cf. the LA Library, where the main reading room was successfully transformed into a children’s library.)”

Figure 2.5: The diagrams demonstrating the ‘high-modernist flexibility’ vs. ‘compartmentalised flexibility’ argument (a refutative enthymeme supported by examples)

(O.M.A, 1999)

“The upper diagram (see figure 2.5a ed.) is what we’ve seen in whole host of contemporary libraries that used high-modernist flexibility, so any activity could happen anywhere. The high modernist would say: ‘we don’t know the future of the library, we don’t know the future of the book, so we’ll use this approach,’ and what we saw were building that were very generic, and worse not only did the reading room look like the copy room, look like the magazine area. It meant that whatever issue was troubling the library at that moment was starting to engulf any other activity happening in it, and what was getting engulfed by the expansion of the book, were these social responsibilities.”

“So we propose what is at the lower diagram (see figure 2.5b ed.), a ‘very dumb’ approach, simply compartmentalise. Put those things what evolution we could predict -and I don’t mean that we’ll say what will actually happen in the future, but we have some certainty of the spectrum of what would happen in the future- put those in boxes designed specifically for it, and put the things we can’t predict on their roof tops. So that was the core idea.”

What happens here is that two lines of argument are contrasted to make one stand out as the right proposition or solution. This is what Aristotle calls a refutative enthymeme which is formed by the conjunction of two incompatible propositions. What is done here is that the proposed solution, ‘compartmentalised flexibility’ stands out as in favour of protecting ‘the responsibilities for social roles for the library’ in contrast with the high-modernist proposition.

But the librarians weren’t convinced yet in the first place, that these ‘social roles’ were part of their mandate.

Joshua Prince-Ramus continues:

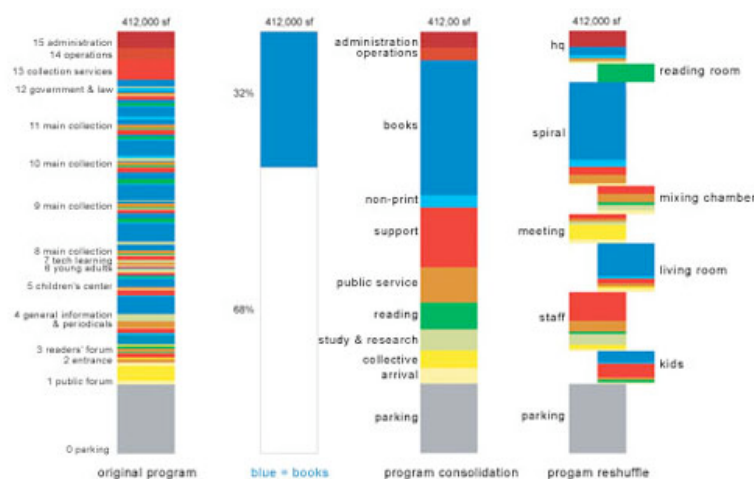


Figure 2.6: The first step (left) the redigestion of the program showing that a third of the program is for books (the blue area). The second step (right): “combining like with like, we have identified five platforms”

(O.M.A, 1999)

“Now we had to convince the library, that social roles were equally important to media in order to get them to accept this. What you’re seeing here is actually their program on the left, that is as it was given to us in all its clarity and glory (see left in figure 2.6 ed.). Our first operation was to re-digest it and show it to them and say: ‘we haven’t touched it, but only one third of your own program is dedicated to media and books, two-thirds of it is already dedicated -that is the white band below- that what you said isn’t important, is already dedicated to social functions (see second bar from the left in figure 2.6 ed.). Once we had presented that back to them they agreed that this core concept could work. We got the right to go back to first principles, the third diagram, that re-combined everything. (see third bar from the left in figure 2.6 ed.) Then we started making new decisions, what you see is the design of the library (see on far right in figure 2.6 ed.), specifically in the terms of square-footage, on the right of that diagram, you’ll see a series of five platforms, combed collective programs, and on the right the more indeterminate spaces, things like reading rooms, who’s evolution in 20, 30, 40 years we can’t predict. So that literally was the design of the building. We came back a week later and presented them this. (see figure 2.7)”

(Prince-Ramus, 2006)

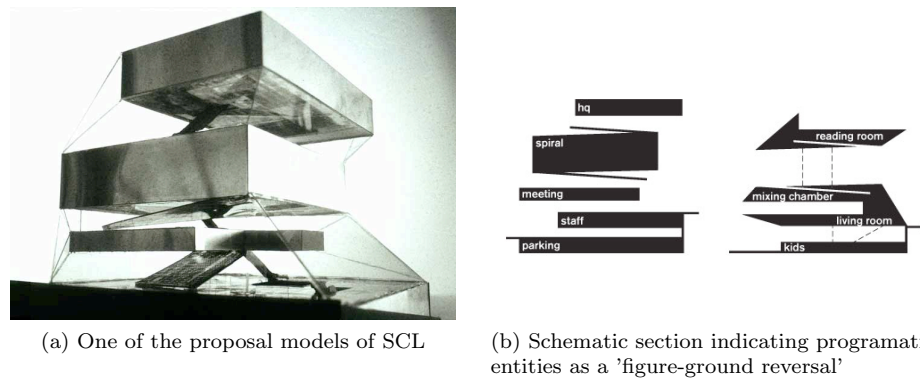


Figure 2.7: The proposed design, 1999
(O.M.A, 1999)

This is the general argument for the overall scheme. Prince-Ramus continues to explain more about why other manipulations in the form, the facade, floorplans, etc. have been done, but I won't dwell on that further. The architectural illustration of the enthymeme in this case is more that sufficient.

Both in Zaera-Polo and Prince-Ramus' case they are involved in a public presentation, they have to explain to an audience or they are negotiating with their clients. While in their respective stories the arguments are clear, we have to be careful in seeing these stories as direct representations of the design process. What we can say is that they both are consciously working towards making the rhetorical argument for their design proposals as strong as possible and as Zaera-Polo explains well in his piece, the consciousness of these rhetoric effects start to have their repercussions on the design process itself, so working towards a rhetorically strong design that performs well in front of different audiences. Prince-Ramus talks about “A hyper-rational process. It's a process that takes rationality to almost an absurd level, it transcends all the baggage that normally comes with what people sort of would call a rational conclusion to something. It

concludes in something that you see here (shows a photograph of SCL ed.), that you wouldn't normally expect as the result of rationality." While the argument as Prince-Ramus unfolds it is clear, one can be very critical about the conclusion.

The conclusion could still result in a building other than the one they proposed. That the combed program diagram (see on the right in figure 2.6) literally translates into the boxes with program on their rooftops seems obvious, but this is very much dependent on the chosen modes of representation.

If one had represented the program as a bubble diagram or a pie-chart would the building than be a huge bubble composition or a giant pie? And even if we stuck with the combed bar diagram, why would one read it as section, and not as a plan, since the bar surface represents square footage floor surface, not volume or wall-surface. While rhetorically this works quite well, it is by no means a logical consequence of the premises. As Prince-Ramus said, the process is hyper-rational, it's rationality to the absurd level.

The problem in this situation is that there are images involved, representation of ideas. This is architecture's problem, but also it's strength as Prince-Ramus cleverly demonstrates. Because while a chosen image can perfectly convey a point, the choice of the image also 'secretly' or implicitly determines the direction of the 'argument' towards a certain design scheme. The problem lies in that an image isn't a rational argument in the first place, an image sometimes appeals to loose conventions, cultural notions, but not strict rules, they are open to interpretation and manipulation. This is why they can be so powerful when used intelligently, but they are also an easy target for those who critique the arbitrary choice of any particular form, because in the end this choice is an arbitrary choice that is not supported by argument.

This is the complicating factor of design, because the conundrum will always be why this shape and not the other? and where to find the arguments to base these choices on? What may be conveyed as a strong rhetoric argument in retrospect has to be constructed beforehand. It has to be constructed in every individual project, but also the skill to do this, to navigate the uncertain terrain of seemingly arbitrary choices has to be constructed through educating and training designers. This brings us back to Schön. In an interview he was asked:

"What do you mean by 'the willing suspension of disbelief'?" That is a phrase of Samuel Taylor Coleridge, a British poet and philosopher from the 19th century, from a text about understanding poetry. To read poetry you have to discard your disbelief because poetry is irrefutably untrue. When you read for example Homer then you know that his statements about Troy are false. So you can say it's nonsense and throw the book away. On the other hand, when you're capable of getting rid of your disbelief -and this doesn't mean that you believe it, but it also doesn't mean you refute it- then you are perhaps capable of searching for the meaning of the poem, through which it eventually becomes true, but in a different meaning truth. Coleridge sees the voluntary discard, the suspension of disbelief as essential for understanding poetry."

(Schön, 1991)

This is the same for understanding architecture, for a project to make sense, you'll have to go with the argument that is embodied in the design. You'll have to embrace it before it can be meaningful to you. Also if one wants to make a critique in a way that is meaningful within architectural discourse one first needs to suspend one's disbelief before one can deconstruct and judge an architectural project.

This is why architecture is such a complicated discipline to learn. Schön explains:

When you transfer this notion [the willing suspension of disbelief ed.] to learning an art or to learning anything that at first seems fundamentally incongruent with

the way a student perceives things, then there will always be an issue of disbelief and doubt. How can a student believe what is taught him if he doesn't understand it, and: how can he understand what is taught him if he doesn't believe it? Before he reaches the moment where he understands, he has to go through a long period where he doesn't really understand what he is doing. (...) Among architects these problems are even larger due to the belief in genius. The student will continue to ask himself: Am I that genius? Do I have those qualities? This has to do with the character of disciplinary knowledge and the difficulty of describing what professional competence is: there is a huge space for mystification."

(Schön, 1991)

While we now have a better understanding of how we should see reasoning in a design context, it doesn't give us much insight into how this reasoning can be operative in the design process. The eventual argument, which is the design itself with its accompanying justification, may have a rhetorical form where words and imagery are intertwined, but before one arrives at this final argument, the final design, one also goes through a process of reasoning. Instead of persuading an audience, the architect has to get convinced him/herself through all the intermediate stages before arriving at the end product. How is this course of actions determined, and how can we explain this in terms of reasoning?

2.2 Reasoning following from intelligence

Reasoning can be more or less understood as formalised operations of human intelligence. This is also the premise from which early A.I. researchers operated, 'the brain must be like a computer'. This (implicit or not) assumes the only form of reasoning in the brain would be deductive in nature. In order to do deduce we have to construct the premise for it with induction, this is also the point where humans come into the equation with intelligent machines, because they provide the premises from which deduction operates, in other words, the program. The best A.I. applications have always been expert systems, machines that are good at one very specific thing, because in that context we can provide them with much better premises in the first place.

If we want to understand the reasoning operative in the design process, we have to look beyond the traditional A.I. approaches into how the human brain actually produces intelligence and thus reasoning. Hawkins' has a similar motivation, he wants to make intelligent machines, but believes we can not do so if we don't understand how our brain produces intelligence in the first place, thus he started to research the brain.

2.2.1 Hawkins' theory of Intelligence

Hawkins explains that intelligence resides in the neocortex. The neocortex literally means 'new bark' and is the youngest part of the brain, the last evolutionary step that sets us apart from our closest evolutionary relative the chimpanzee. The human neocortex is three times as large as that of the chimp. One can say roughly that in the case of the neocortex that the quantity of 'grey matter' that we have is what makes us so much more intelligent than, let's say, a monkey. Under this new layer, we have much more in common with other species, this is where the old brain is, the brain that we have in common with many species. It is also referred to as 'the lizard brain'. The neocortex is the wrinkly outer layer of your brain (see figure 2.8). It is wrinkly because, as Jeff Hawkins says: "its too big and doesn't really fit in our skull(Hawkins & Blakeslee, 2004). If you would iron out all the wrinkles you would have a large dinner napkin sized sheet (50x50cm).

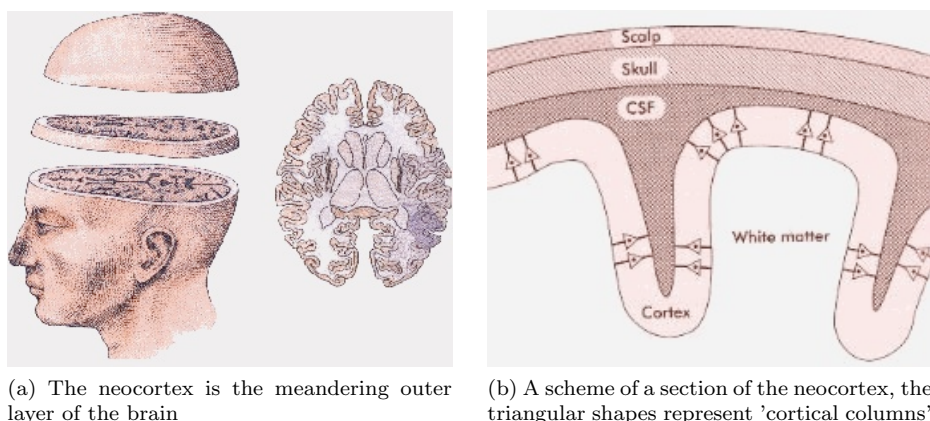


Figure 2.8: The brain

The fundamental anatomical structure is basically the same everywhere in the neocortex, but through genetically determined guidelines and through life experience your brain gets wired up in a certain way. This is why you have specific regions in the brain dealing with sensory functions such as smell, vision, touch, hearing, taste, and motor functions that control your movement of your legs, arms, fingers etc. The neocortex also developed highly specialised areas of the brain, for recognising faces for instance. The basic anatomical structure of the neocortex is not different in such areas than it is in the touch area, facial recognition, or the 'moving your arm' area. In 1978 the neuroscientist (and Nobel laureate) Vernon Mountcastle published a paper titled *An Organising Principle for Cerebral Function* (Mountcastle, 1978), making exactly this point that the neocortex is remarkably uniform in appearance and structure (see figure 2.9). In the paper he proposes that the cortex uses the same computational tool to accomplish everything it does. Hawkins builds upon this neuroscientific notion in support of his theory of intelligence.

Besides the homogenous character of the neocortex there is another overall characteristic, namely that it only deals with patterns, patterns stored in our memories and patterns coming in through our senses. The elements that our neocortex's processes, or in other words what we thinks 'with', are patterns and that what the neocortex can do with patterns is what constitutes intelligence. Such operations are relatively simple in their fundamental principles, but complex in their consequences. These patterns are dealt with in a certain way, Hawkins states four guiding principles concerning patterns:

1. The neocortex recalls patterns auto-associatively.
2. The neocortex stores sequences of patterns.
3. The neocortex stores patterns in an invariant form.
4. The neocortex stores patterns in a hierarchy.

So there are three principles characterising the organising structure in which these patterns are stored, and there is one principle that determines how this structure is navigated: this is auto-association.

Auto-association

Auto-association is a notion that originates from a small splinter group of neural network theorists who built networks that didn't focus on behaviour. Hawkins first learnt about this through

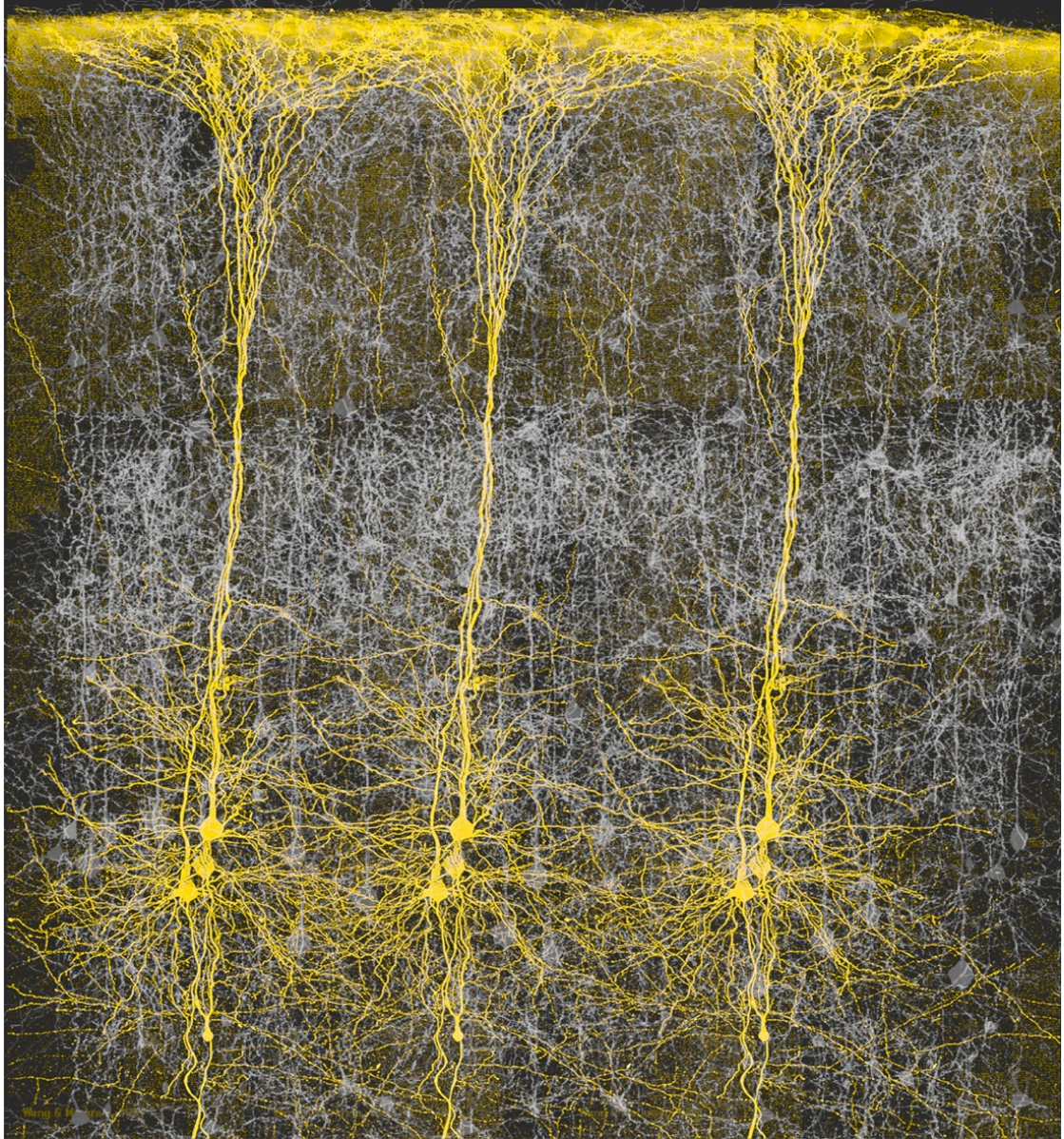


Figure 2.9: In this image three cortical columns, consisting each of many neurons and nodes, are highlighted from a vast forest of neurones (also organised in a columnar structure) that one can still recognise in the background

Tuevo Kohonen's book *Self-Organization and Associative Memory* (Kohonen, 1984) and through simulation experiments by Gerd Willwacher (Willwacher, 1982). They developed something they "called auto-associative memories, they were also built out of simple 'neurons' that connected to each other and fired when they reached a certain threshold, but they were interconnected differently, using lots of feedback. Instead of only passing information forward, as in a back propagation network, auto-associative memories fed the output of each neuron back into the input -sort of like calling yourself on the phone. This feedback loop led to some interesting features. When a pattern of activity was imposed on the artificial neurons, they formed a memory of this pattern. The auto-associative network associated patterns with themselves, hence the term auto-associative memory." (Hawkins & Blakeslee, 2004) So with this auto-associative memory system they created a system that could genuinely learn something, this was a breakthrough, because this was impossible with computer program based systems. Besides this basic finding some other properties of this auto-associative system were found. "The most important property is that you don't have to have the entire pattern you want to retrieve in order to receive it. You might have only part of the pattern, or you might have a somewhat messed-up pattern. The auto-associative memory can retrieve the correct pattern, as it was originally stored, even though you start with a messy version of it." (Hawkins & Blakeslee, 2004) Auto-association recreates the whole from merely from its small parts. This is something we constantly do in our sensory perception of our world, we constantly complete patterns. "If you see your child's shoes sticking out from behind the draperies, you automatically envision his or her entire form. You complete the spatial pattern from a partial version of it. Or imagine you see a person waiting for a bus but can only see part of her because she is standing partially behind a bush. Your brain is not confused. Your eyes only see parts of a body, but your brain fills in the rest, creating a perception of a whole person that's so strong you may not realize you're only inferring." (Hawkins & Blakeslee, 2004) Besides spatial patterns we also complete temporal patterns. "During conversation we often can't hear all the words if we are in a noisy environment. No problem. Our brains fill in what they miss with what they expect to hear. It's well established that we don't actually hear all the words we perceive. Some people complete other's sentences aloud, but in our minds all of us are doing this constantly. And not just the ends of sentences, but the middles and beginnings as well. For the most part we are not aware that we're constantly completing patterns, but it's a ubiquitous and fundamental feature of how memories are stored in the cortex." (Hawkins & Blakeslee, 2004)

Sequence

A second important property found by the neural network researchers that were working on auto-associative memory was that you could design this type of neural network to store sequences of patterns, so in other words time was introduced in this type of neural network configuration. "This feature is accomplished by adding a time delay to this the feedback. With this delay, you can present an auto-associative memory with a sequence of patterns, similar to a melody, and it can remember the sequence. I might feed in the first notes of 'Twinkle Twinkle Little Star' and the memory returns the whole song." (Hawkins & Blakeslee, 2004) For humans it is very hard to understand something if it is not in a sequence, memories unfold in a sequential fashion, stories do, even visual information is navigated by sequence, we have to 'read an image'. Memories are stored like this in our brain, for example try saying the alphabet backwards. This is very hard, and very counter intuitive. "All memories are like this. You have to walk through the temporal sequence of how you do things. One pattern (approach the door) evokes the next pattern (go through the door), which evokes the next pattern (either go down the hall or ascend the stairs), and so on. Each sequence you've followed before. Of course, with conscious effort I can jump from basement to the second floor if I decided to focus on items in a nonsequential way. Yet once

I start to describe any room or item I've chosen, I'm back to following a sequence. Truly random thoughts don't exist. Memory recall almost always follows a pathway of association. (Hawkins & Blakeslee, 2004)

Invariance

While the auto-associative memories demonstrate some of the fundamental features of real neurons in the brain they also fail at a very basic feature, namely dealing with patterns in an invariant manner.

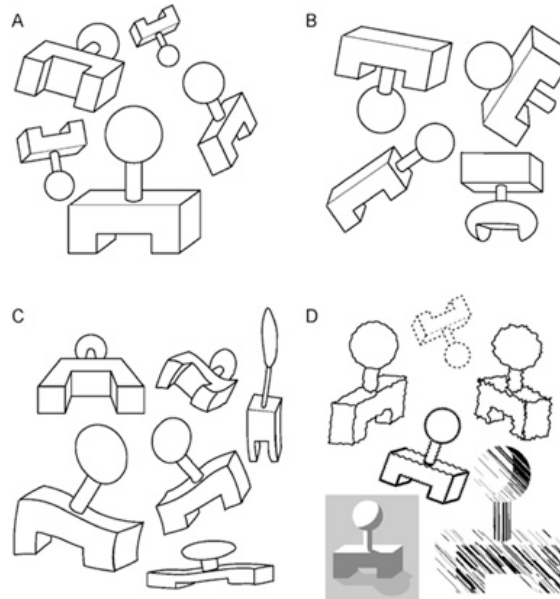


Figure 2.10: We perceive objects as the 'same' object although they have been manipulated in various ways. The objects in figure *A* are all immediately recognised as the same basic shape, which are immediately distinguishable from the forms in *B*. They are recognised despite perspective and elastic deformations as in *C*, and when depicted using different graphic elements as in *D*. This phenomena is know as *invariance*

Invariance is one of the capacities of the brain originally described in Gestalt psychology. Invariance is a property of perception in which objects are recognised independent of rotation, translation, and scale; as well as several other variations such as elastic manipulations, different lighting, and different component characteristics, see figure 2.10. Auto-associative memories for instance can recognise a picture of a face if you only give half of the picture, but if you move the whole face in the picture by a few pixels it will fail to recognise, while humans wouldn't probably perceive the shift of the face by a few pixels. But how does this work in our brain? "We know from experiments that if we monitor the activity of neurons in the visual input area of your cortex, called V1, the pattern activity is different for each different view of her face. Every time the face moves or your eyes make a new fixation, the pattern of activity in V1 changes, much like the changing pattern on the retina. However, if we monitor the activity of cells in your face recognition area - a functional region that's several steps higher than V1 in the cortical hierarchy we find stability. That is, some set of the cells in the face recognition remain active as long as your friend's face is anywhere in you field of vision (or even being conjured in your mind's

eye), regardless of its size, position, orientation, scale, and expression. This stability of cell firing is an invariant representation.”(Hawkins & Blakeslee, 2004) Invariance is not limited to vision, all senses have this characteristic. For instance hearing: we recognise the melody of a song independent from the key it is in, most of us wouldn’t even notice that the key of a song would be different from the first time you heard it (with exception of those who have perfect pitch). Hawkins believes that this abstraction of form is happening throughout the neocortex and is a general property of the brain. “Memories are stored in a form that captures the essence of relationships, not the details of the moment. When you see, feel , or hear something, the cortex takes detailed, highly specific input and converts it to an invariant form, It is the invariant form that is stored in memory, and it is the invariant form that of each new input pattern that it gets compared to. Memory storage, memory recall, and memory recognition occur at the level of invariant forms.(Hawkins & Blakeslee, 2004)

Hierarchy

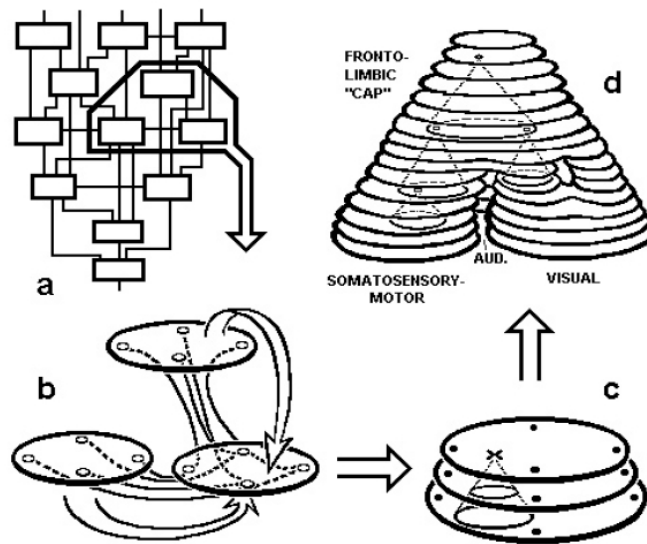


Figure 2.11: The cortical hierarchy of our brain

The phenomenon of invariant representation already hints at the hierarchical structure of how our brain is organised. That our brain is an hierarchically organised memory system is one of the most important concepts in Hawkins’ intelligence theory, let’s shortly explain what this looks like. It all begins with a pattern. A pattern is the collective activity of a bundle of fibers (axons), from let’s say your eye. The pattern travels trough the fibers and arrives at the lowest sensory region of the cortex, in this case V1. The pattern can be spatial, which means the pattern of an instant (the moment your eye focuses on an object), and temporal, which means how the activity of fibers changes over time (when your eye moves across an object). In this fashion all our senses bring patterns to our neocortex. Our neocortex is a network of regions, each one of them is dedicated to processing patterns at a certain level in the cortical hierarchy, *a* in figure 2.11 represents this network, to make a more insightful scheme in order to represent the hierarchy of these regions better we can stack these regions according to the levels they are processing at (*a* and *b*), so raw sensory input enters the neocortex at the bottom level where

patterns are fast changing (because the eye moves three times per second) and the focus is on details like edges and line fragments and very specific characteristics of what one sees. When one goes up to higher levels in the hierarchy, lines, become shapes, shapes become parts of an object, you start to recognise specific objects and the perception is much more stable than in the lower levels. All this results in an hierarchical organisation as seen *d* in figure ??, where different sensory inputs come together, feedback on each other, and create a unified sensory experience, presenting us a stable world, not a continuous bombardment of sensory input.

What actually happens is that every level in the cortical hierarchy makes an ‘invariant representation’ of the one below. At the lowest cortical levels information is changing all the time and the focus is only on details, at the higher cortical levels information becomes more stable, information is not changing all the time, one’s environment is understood and the world is made of objects, instead of an ocean of details.

In figure 2.12a you see arrows going up as well as arrows going down. Up arrows consist of information flowing up the hierarchy, which is also known as ‘feedforward’ which consists of information from sensory input. Down arrows signify information flowing down the hierarchy, also known as ‘feedback’ which is the prediction information. Based on what is forwarded from the senses, certain networks of neurons fire and feedback is triggered, the feedback is the flow of information that constitutes the actual prediction in the brain. What is important to know is that the relation between these feeds is not simply 50/50. The brain has roughly ten times more feedback connections than it has feedforward connections. As Hawkins says: Prediction is so pervasive that we ‘perceive’ that is, how the world appears to us- does not come solely from our senses. What we perceive is a combination of what we sense and of our brains’ memory-derived predictions. (Hawkins & Blakeslee, 2004)

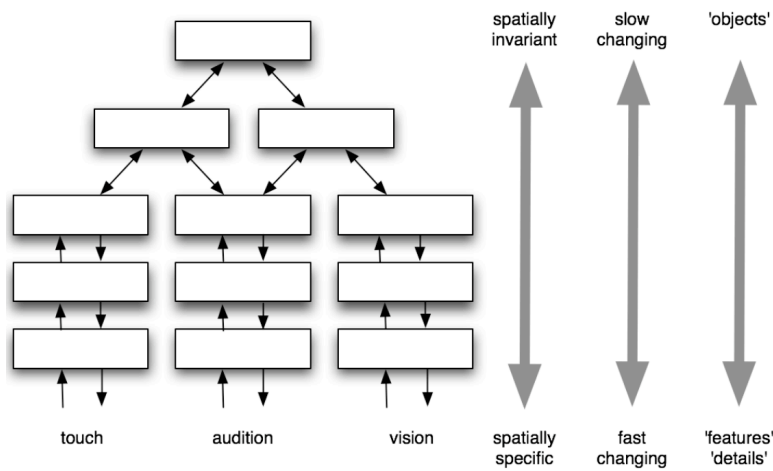
But what does it mean that the brain is a series of hierarchically stacked invariant representations? Hawkins’ explains:

”the cortex’s hierarchical structure stores a model of the hierarchical structure of the real world. The real world’s nested structure is mirrored by the nested structure of your cortex (see figure 2.12b ed.) .

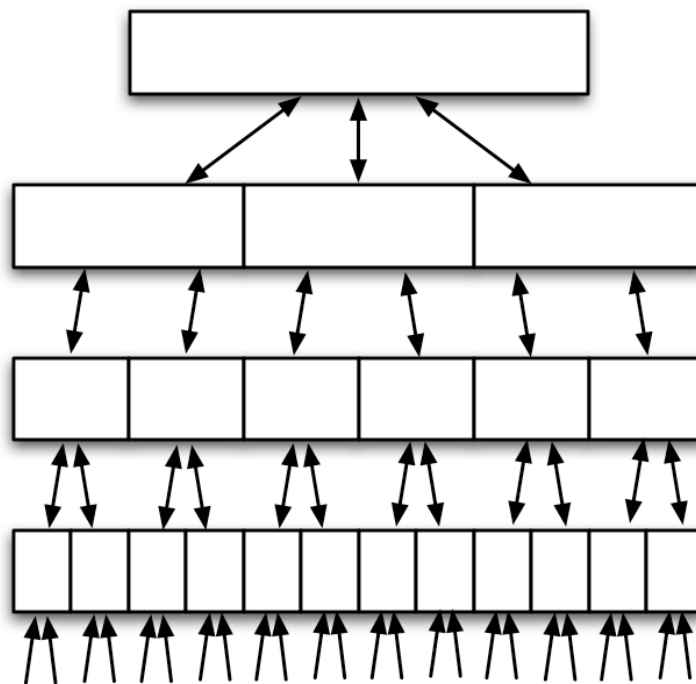
(...) Think about music. Notes are combined to form intervals. Intervals are combined to form melodic phrases. Phrases are combined to form melodies or songs. Songs are combined into albums. Think about written language. Letters are combined to form syllables. Syllables are combined to form words. Words are combined to form clauses and sentences. Looking at it the other way around, think about your neighborhood. It probably contains roads, schools, and houses. Houses have rooms. Each room has walls, a ceiling, a floor, a door, and one or more windows. Each of these is composed of smaller objects. Windows are made of glass, frames, latches, and screens. Latches are made from smaller parts like screws.

Take a moment to look up at your surroundings. Patterns from the retina entering your primary visual cortex are being combined to form line segments. Line segments combine to form more complex shapes. These complex shapes are combining to form objects like noses. Noses are combining with eyes and mouths to form faces. And faces are combining with other body parts to form the person who is sitting in the room across from you.

All objects in your world are composed of subobjects that occur consistently together; that is the very definition of an object. When we assign a name to something, we do so because a set of features consistently travels together. A face is a face precisely because two eyes, a nose, and a mouth always appear together. An eye is an eye precisely because a pupil, an iris, an eyelid, and so on, always appear together.



(a) How different levels in the cortical hierarchy 'perceive' patterns differently, and how this at the top of the hierarchy results in a unified experience of the world.



(b) Hawkins' depiction of the hierarchical memory system. Every level makes invariant representations of the one below. Sensory patterns are fed forward, up the hierarchy; and predictions are fed back down the hierarchy.

Figure 2.12: The brain's hierarchical structure

The same can be said for chairs, cars, trees, parks, and countries. And, finally, a song is a song because a series of intervals always appear together in a sequence.

In this way the world is like a song. Every object in the world is composed of a collection of smaller objects, and most objects are part of larger objects. This is what I mean by nested structure. Once you are aware of it, you can see nested structures everywhere. In an exactly analogous way, your memories of things and the way your brain represents them are stored in the hierarchical structure of the cortex. Your memory of your home does not exist in one region of cortex. It is stored over a hierarchy of cortical regions that reflect the hierarchical structure of home. Large-scale relationships are stored at the top of the hierarchy and small-scale relationships are stored toward the bottom.

The design of the cortex and the method by which it learns naturally discover the hierarchical relationships in the world. You are not born with knowledge of language, houses, or music. The cortex has a clever learning algorithm that naturally finds whatever hierarchical structure exists and captures it. When structure is absent, we are thrown into confusion, even chaos.”

(Hawkins & Blakeslee, 2004)

2.2.2 Similarities between Hawkins’ *Intelligence* and Schön’s *Reflection-in-Action*

How can Hawkins’ theory of intelligence help in refining Schön’s framework of reflection-in-action in order to come to an understanding of how reasoning would work in design. First of all let us compare Hawkins and Schön and see in what way they are similar.

Schön (1983) Reflection-in-action	Hawkins (2004) Intelligence
<i>repertoire</i>	<i>memory</i>
+	+
<i>seeing-as and doing-as</i>	<i>prediction through analogy to the past</i>
+	+
<i>back-talk</i>	<i>affirmed/ violated prediction</i>
=	=
<i>reflection-in-action</i>	<i>intelligence</i>

Schön’s reflection-in-action consists of three elements:

1. *Repertoire*. This is the accumulated knowledge and experiences of a practitioner. ”The practitioner has built up a repertoire of examples, images, understandings, and actions. Quist’s [the architecture teacher in Schön’s research ed.] repertoire ranges across the design domains. It includes sites he has seen, buildings he has known, design problems he has encountered, and solutions he has devised for them.(Schön, 1983)

2. *Seeing-as and doing-as.* This is how past experience, thus repertoire, is brought to bear on new and unique situations. This is determined by the analogical operations of seeing-as and doing-as. “When a practitioner makes sense of a situation he perceives to be unique, he sees it as something already present in his repertoire. To see this site as that one is not to subsume the first under a familiar category or rule. It is rather, to see the unfamiliar, unique situation as both similar to and different from the familiar one, without at first being able to say similar or different with respect to what. (...) Seeing this situation as that one, one may also do in this situation as in that one. (...) the whole process of seeing-as and doing-as may proceed without conscious articulation.” (Schön, 1983)
3. *Back-talk.* This is the ‘feedback’ the practitioner receives from his actions (doing-as), how he experiences, and thus intuitively judges this feedback, is determined by his appreciative system. The appreciative system is part of the repertoire, part of how he ‘understands’ the situation. “The evaluation of the frame experiment is grounded in the practitioner’s appreciative system. Through the unintended effects of action, the situation talks back. The practitioner, through reflection on this back-talk, may find new meanings in the situation which lead him to a new reframing. Thus he judges a problem-setting by the quality and direction of the reflective conversation to which it leads. This judgement rests, at least in part, on his perception of potentials for coherence and congruence which he can realize through his further inquiry.” (Schön, 1983)

Likewise we can also break Hawkins’ intelligence model up in three similar elements, and show how this can help us in refining Schön’s theory.

1. *The Brain’s Memory.* This is the accumulation of all our experiences and knowledge, or as Schön calls it repertoire. What is interesting here is that Hawkins gives us a lot more characteristics of how these experiences and knowledge are organised in our memory. The storage of memories or patterns in our neocortex is done in sequences, in invariant form and in a hierarchy as we’ve shown earlier. With Hawkins’ theory we can get more insight in how the practitioners ‘appreciative system’ (as Schön calls it) works and how it helps in judging his actions, in dealing with ‘back-talk’. We will go into this later.
2. *Prediction through analogy to the past.* Through association our memory, in other words our past, is navigated in search for patterns that match the situations we encounter. Then, through analogy with existing memory patterns in our neocortex, our brain predicts (aware and unawarely). This is similar to seeing-as and doing-as. The repertoire is the past, the accumulated memory patterns in our brain. By analogy to these existing patterns, the practitioner sees-as and does-as similar to those existing patterns. Because Schön’s practitioner bases these actions on what he knows, he also has an idea of what is going to happen when actions unfold. The practitioner has an idea of what is going to happen, this in essence is a prediction.
3. *Affirmed and violated predictions.* An affirmed prediction results in understanding, a violated prediction in confusion. Confusion pushes one to think harder, because you ‘want’ to find a matching pattern, you try to understand. This is what happens according to Hawkins: “Think about information flowing from your eyes, ears, and skin into the neocortex. Each region of the neocortex tries to understand what this information means. Each region tries to understand the input in terms of the sequence it knows. If it does understand the input it says, ‘I understand this, it is just part of the object i’m seeing. I won’t pass on the details.’ If a region doesn’t understand the current input, it passes it up the hierarchy until some higher region does. However, a pattern that is truly novel will

escalate further and further up the hierarchy. Each successively higher region says, ‘I don’t know what this is, I didn’t anticipate it, why don’t you higher-ups look at this?’ The net effect is that when you get to the top of the cortical pyramid, what you have left is information that can’t be understood by previous experience. You are left with that part of the input that is truly new and unexpected.”(Hawkins & Blakeslee, 2004) At the top of this hierarchy is a brain area called the hippocampus, if the pattern couldn’t find a match in an existing memory, the pattern becomes a new memory in the hippocampus. This process of patterns escalating up the hierarchy in search for a match, is foundational for experiencing the unexpected, a sense of surprise. Because what is initial confusion at first can be resolved when it a match in ‘second instance’ is found. Violating predictions in this sense is fundamental for experiencing something like humour for example. Also this ‘search’ for a match is a process through which we can understand something in a different way, when a new match (sooner or later) is found. This is what happens in what Schön describes as back-talk. One frames a situation in a certain way, which implies a certain appreciative system. Within this frame one experiments through actions, within these actions the hypothesis is implicitly embedded. The violation or confirmation of the prediction, which the hypothesis is, is determined by the appreciative system. The unintended, thus unexpected results of the actions leads to a re-appreciation of the situation and as such evolves one’s understanding of the situation and in turn again contributes in evolving one’s appreciative system.

When we project the categories of knowledge and thinking on this comparison we see that, both repertoire and memory represent knowledge. Thinking on the other hand is represented by Schön’s seeing-as and doing-as in combination with back-talk and Hawkins’ affirmed or violated predictions made by analogy to the past. What we can also see very strongly, is the indivisibility of knowledge and thinking, our reasoning is guided by the our appreciative systems and repertoires. Or as Hawkins writes: “Truly random thoughts don’t exist. Memory recall almost always follows a pathway of association.”(Hawkins & Blakeslee, 2004) Association in turn is determined by analogy, the analogical actions of matching what exists outside our mind to what already exists inside our minds, but analogical relations also connect everything that is in the mind with each other. This notion is also the basis of Douglas Hofstadter’s conviction that practically all cognition is based on analogy. “every concept we have is essentially nothing but a tightly packaged bundle of analogies, and to suggest that all we do when we think is to move fluidly from concept to concept in other words, to leap from one analogy-bundle to another and to suggest, lastly, that such concept-to-concept leaps are themselves made via analogical connection”(Hofstadter, 2001) When we concern reasoning, this means that in reality the brain performs the various modes of reasoning as a type of analogical operation, one way or another.

2.2.3 Reasoning as Analogical Operations

We can explain reasoning as analogical operations. When analogy is the guiding principle determining how every pattern finds it’s match, independent of whether this is within an imaginary train of thought or when patterns in the brain find their matches with patterns outside the brain. We will take deductive, inductive and abductive reasoning, and explain them as analogical operations, in other words, as processes of matching patterns, based on certain level of similarity. Neither of these forms of reasoning is devoid of context, in other words they are always situated. This situation can be imaginary or real. One could position the three modes of reasoning on a scale stretched between the polarities of strong inference and weak inference, between deep familiarity with the situation and unfamiliarity with the situation. With on one end deduction, the other end abduction and in the middle induction.

Deduction as Analogical Operation

If one applies deductive reasoning to deal with a certain situation, it is important that one mentally 'projects' the right assumptions on a situation. A conclusion following from deduction can only be true if the assumptions are true. Making the right assumptions about an encountered situation thus determines the power and validity of the conclusion concerning that situation.

Deductive reasoning only deals with what we deeply understand about a situation. In terms of Hawkins' intelligence model, understanding results from predictions that are affirmed, that are correct. If predictions are affirmed we don't question reality, we are not confused about it. This means that patterns immediately find matches in the brain, this means there is a very fixed reading of the situation encountered. For example when a mathematician encounters an algebraic formula, he will be able to read it in full understanding, because the underlying structure, the ordering principles and the signs and symbols that represent these are all very familiar to him, he uses them on a daily basis thus they are firmly 'present' in his brain. The mathematician is not wondering if a certain symbol really represents this or that. Because the mathematician is absolutely familiar with what he sees, he is very certain in his thoughts, there is no doubt, instead there is truth, thus he can perform deductive reasoning. He can extract elements from what he observes and pose them as premises. From these premises, i.e. truths, that are extracted from a deeply familiar situation, deduction can unfold. This works the same for any situation one is deeply familiar with, this is also why deduction only works when one has firmly internalised a certain way of reading certain situations, in the case of the mathematician, the system of mathematics. This goes for any disciplinary field. One can only use deduction when one is deeply familiar with the situation, because deduction only succeeds when the 'projected' structure that is in the mind finds a match with the structure that is found external to the mind. This is why deduction works best in very exact and ordered structures such as mathematics and language. This also works the same way in architectural design, or any other profession. The more familiar you are with a situation, the easier it is to make statements about them, but

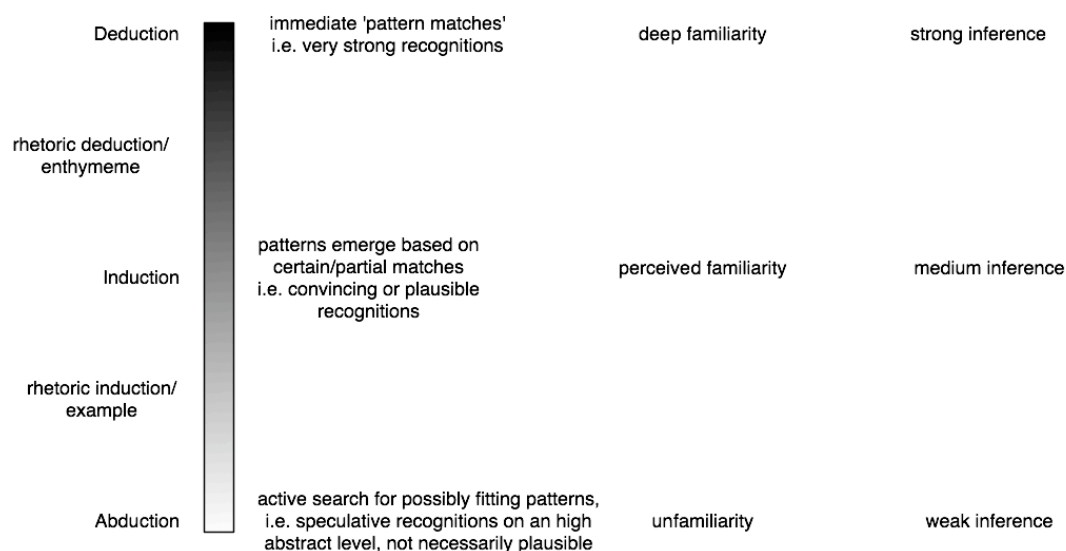


Figure 2.13: A scale of various modes of reasoning

because reality is usually more ‘messy’ or ‘wicked’ than an algebraic equation, structures don’t have to have exact matches, but do have a lot of partial and incomplete matches which are very convincing but don’t ‘feel’ like absolute truths. This changes the use of deduction to a more rhetorical nature, where deductive arguments become enthymemes and premises maxims, as we have shown earlier in this chapter.

Induction as Analogical Operation

Inductive reasoning is much more based on active perception, one seeks to recognise something as familiar, one seeks an answer to how one should read a pattern. One makes an effort to find a way to understand the situation. There is not an obvious and immediate pattern match as is the case with deductive reasoning, but the effort of finding analogy between what one knows and what one perceives is an active effort to familiarise oneself with the situation, to find a way of understanding. Inductive reasoning ranges from the repetitive observation of similar situations, to just one or a few observations of similar situations. The power of induction is strongest when the observations have been extensive, and not based on just a few instances. From these specific instances of observation finally generalities can be abstracted, statements that on a certain level of abstraction seem to be true for all observations. Thus when one bases a process of familiarisation on a few observations one is bound to stay closer to what one already knows, but if one actively familiarises oneself through repeated exposure to a situation, one is actually learning something new. The brain starts making new patterns, and invariant representations of what one has observed (Hawkins & Blakeslee, 2004). Repeated exposure to new patterns is also the foundational concept of how the brain learns, this is also known as Hebbian learning. In this way one can understand inductive reasoning as a precursor of deductive reasoning, because induction is the process of actively familiarising oneself with something (i.e. learning), in other words constructing the structures of patterns that are needed for the ‘deep familiarity’ that is necessary for deduction. Induction generates the premises needed for deduction. When we look at the practical application of induction we know that induction based on an extensive amount of observations is the norm for science, where practitioners, like architects use inductive reasoning based on a few observations, depending on the experience of an architect. This again comes closer to the rhetoric use of induction one or a few examples that make or support a rhetoric argument.

Abduction as Analogical Operation

Abduction is the weakest of the three forms of inference (deduction, induction and abduction), and that one uses it when one is trying to understand something that one is unfamiliar with. Still one seeks to find probable explanations, in this sense abductive reasoning is also the most synthetic mode of reasoning. One seeks to unite disparate entities in a unifying structure, in other words, one seeks to find a shared analogy, an invariant representation that explains the relations between such seemingly disparate entities. This is also one of the ideas Peirce had about abduction, although in this quotation he refers to it as ‘hypothesis’:

“The function of hypothesis is to substitute for a great series of predicates forming no unity in themselves, a single one (or small number) which involves them all, together (perhaps) with an indefinite number of others. It is, therefore, also a reduction of a manifold to unity.” (Peirce EP 2:34, 1868; see also e.g. Peirce W 1:516, 1866) as cited in (Paavola, 2006)

One could see this perhaps as an effort of the mind to make oneself familiar with something on a very high-order level, by using abstraction, i.e. high invariant representations that belong to all kinds of other fields, disciplines and situations that in a direct sense bear no similarity

with the situation one seeks to understand. In this sense one could see it as an extension of the rhetorical example, 'this is like that', thus an analogy is made, but on a higher abstraction level.



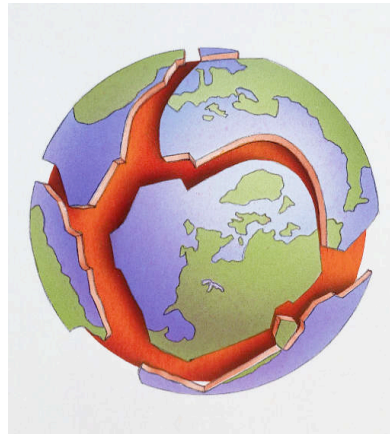
(a) A photograph of the vascular system



(b) Highway node in Los Angeles.



(c) A photograph of ice shelves



(d) The Earth's tectonic plates

Figure 2.14: The analogies that connect these images work through the shared invariant representation they have on a high level of abstraction. That they look similar in some ways is only because the enormous difference in scale in these images has been 'removed'.

While our vascular system, in a direct way, has nothing in common with our transportation systems, they start resembling each other more on a higher abstraction level, when one ignores a lot of detail such as scale and one is a biological and the other a technological structure. A similar example of a shared higher abstraction through which the analogy operates, is comparing the theory of tectonic plates with the dynamics of floating ice shelves.

There is another characteristic of abduction which is important to us, and this has more to do with the speculative nature of these highly abstract and often initially far fetched analogies. This has to do with abduction being a kind of reasoning that works backwards, starting at the consequence or conclusion and from there speculating about what the causes or premises of that consequence could be. In this quotation Peirce uses the term 'retroduction' for abduction in

which ‘retro’ also reflects the ‘backward’ nature of this reasoning:

“I have on reflexion decided to give this kind of reasoning the name of retroduction to imply that it turns back and leads from the consequent of an admitted consequence, to its antecedent.” (Peirce MS 857:5, n.d.; cf. also MS 756:v3-5) as cited in (Paavola, 2006)

Peirce also uses words such as guessing and “may-be’s”, and when we also take into account that Peirce presented abduction as “closely related to many kinds of cognitive processes, such as instincts, perception, practices and mediated activity in general.” (Paavola, 2006) One could easily replace Peirce’s “may-be’s” with Schön’s “what if’s”, but the fact that Peirce also thought about abduction as a mediated activity draws some parallels with what Schön reflection-in-action. For the architect the medium would obviously be the drawing or model, through which he reflects and adjusts his actions depending on the kind of ‘back-talk’ he receives from his ‘what if’ moves.

2.3 Reasoning in Architectural Design

When we project these definitions of the various modes of reasoning as analogical operations on the design process, we have to consider at least two levels where such reasoning operates. This mainly has to do with different scale levels of time - the time frame of the architects life, and that of the project. It is important to acknowledge that you cannot confine reasoning in a model that limits the time dimension in an absolute way.

2.3.1 Architectural Deep Familiarity

Deductive reasoning can only be used when one has learned, induced, ‘built up’ this knowledge in the mind, when one has established a deep professional familiarity with architecture. This build up of knowledge is not easily confineable to just a period of professional education, and experience in practice. Although these are the most important in defining the disciplinary dimensions of architectural knowledge, one cannot ignore the rest of an architect’s life in having, in certain ways, an influence on deeply established ideas and notions that directly influence how he designs or thinks about architecture. Christian Rapp has worked as mason, Rem Koolhaas was a journalist and filmmaker, Peter Zumthor is the son of a cabinet maker and learned carpentry at an early age, and Daniel Libeskind was a virtuoso musician and the son of Holocaust survivors. Such biographical facts are retraceable in the architectural works of these architects and how they talk and write about their work.

The origins of architectural works are not retraceable to mere biographical facts, what I want to show is that every architect has a different repertoire that is not necessarily only a strict professional one, but still these are deep familiarities to them, and experiences they will bring to bear on architectural situations. Besides taking into account repertoire beyond experiences within architectural practice and education, we also have to acknowledge differences in practice and education themselves. Architectural schools have a lot of general similarities, but are also radically different when taking into account the variety of architecture schools that exist over the globe. Architecture is differently taught in an academy, a polytechnic school, a university, but also differently in Russia, than in France, than in the U.S. and than in the Netherlands. The same goes for practices O.M.A, will work differently than SANAA, than Greg Lynn, than Jerde and in this sense practices are in their own sense again schools. All these differences don’t prevent architects globally from studying in each others’ schools, and working in a vast array of globally distributed practices. While there is often miscommunication, cultural differences, and a Babylonian confusion between the architectural lingo spoken in one practice with the other practice, there is still a common basis of understanding. I think this common basis lies in the

tools and media we use to mediate ideas and develop them. One cannot design without putting it on paper sooner or later, since one has to work towards construction drawings. Thus the deep familiarity all architects share is the understanding of the architectural drawing, how to read it, understand it, make it and develop it. Understanding how elevations, sections, plans, details, and perspectives all relate to each other. Besides the drawing, there is the model, which presents architects with a scaled down but experientiable rendering of possible designs, or even 1:1 mock-ups of facades, or interiors to get a physical idea of what a space would be like. Also the digital means of representation, drawing, 3D rendering and from that again 3D printing. Whilst through the proliferation of new media the architects' means of dealing with architecture are extending, the core of our architectural system of representation, or one could even say our lingua franca, currently consists of the drawing and the model. While acknowledging this as a common denominator in architecture, this absolutely cannot account for the variety of architectural production that we witness today, this we can account to the various schools architects went to, the offices they practised, their previous careers, and their life experience.

2.3.2 The Architectural Design Process

While the previous section describes the expanse and nature of knowledge that architects bring to bear on individual design projects, how this knowledge is activated and becomes operational in individual projects is what I'll describe here. The individual design project, a process that runs from an initial briefing to completion of the final design (and all its associated documents and drawings), can also be understood as consecutive phases in which certain types of reasoning are more dominant than others. This does not mean other modes of reasoning are completely absent. Since the three modes of reasoning don't operate in complete isolation from each other, and not in a very neat and discrete fashion, we shall represent the process as a progression along two scales. A scale with the beginning of the design process on one side and the termination of the design process on the other side, and another scale along which the types of reasoning are ordered according to the power of inference, at the top deductive reasoning, and at the bottom abductive reasoning.

Every design starts with a limited amount of information, typically the site and the brief, and ends with an enormous amount of drawings, permits, models, calculations and more. From a very low definition of a building, the process progresses towards a very high definition of the building. One works from low resolution to high resolution. A design process manages to transform a site and a brief to a final building design, what is added to this equation is the architect's knowledge, the repertoire in his brain. The architect is an active entity that transforms this little bit of information into a building, through actively mobilising his knowledge.

When we look at the starting point of the design process, one can often deal in a deductive fashion with the brief, one can analyse the program, the square footage, the budget and the functions. The site, and its context, can be analysed to a certain extent in a deductive fashion, one can analyse the allowed envelope dimension, urban fabric, relations to transportation, vistas, underground infrastructure, etc. What results from this are pre-conditions for a design, things that have to be taken into account, that unavoidably must be dealt with one way or another (conscious ignorance is also a way of 'dealing with things'). From these pre-conditions, or premises one can work, for instance, in a rhetorical fashion, as shown in the Seattle Central Library example, postulating from the briefing and site certain maxim's from which certain design choices unfold. This is but one way to proceed, the framework created by site and briefing analysis, can just as well be understood as the definitions of the size and nature of the architects 'canvas', but within the canvas, there is again freedom, a 'blank sheet'.

What we can conclude from this is that the initiation of the design process, at least in

the reality of practice that is, starts with understanding the arena one is in, in other words understanding the brief and the site. After understanding the brief and site, different practices take different courses of action. Some take the program as the main driver for the design process, others the site, some both, some neither. Thus how deductive conclusions from reviewing the briefing and site are used is radically different, different architects might end up with different conclusions from identical sites and briefings (one just has to imagine the variety of designs proposals in design competitions). What we can say in general is that the brief and site are preconditions for the design process, and that no building design can be objectively determined from these preconditions, excluding the fact that the form would be completely determined in the brief itself, but then there wouldn't be much left to design in the first place.

The second phase in the design process starts somewhere in the lower regions of weak inference, perceived familiarity and the unfamiliar, thus abduction and rhetorical induction (examples). This is where the preliminary sketching and model-making takes place, where one tries to synthesise the disparate facts in the brief, and the realities of the site, into a unifying scheme. This is abductive reasoning, carried out through a reflective conversation with the situation, which is mediated in drawings and models. In this process, continuous examples come to mind from the architect's repertoire in which he observes similarities in the sites he has seen before, building typologies which match the program and/or the site, referencing projects from books and magazines. During this phase, the lines evolve from scribbles, to ruler drawn lines, to lines drawn in the computer, and complete 3D computer models.

What happens is that we escalate further and further up the scale to stronger inferences, association cycles go from open to more and more closed associations, because the 'design is closing in', the design gets more defined, it moves more and more out of the regions of low definition closer to high definition. This also makes stronger forms of induction possible, and comes closer to rhetorical deduction. The design can now be understood on various levels,

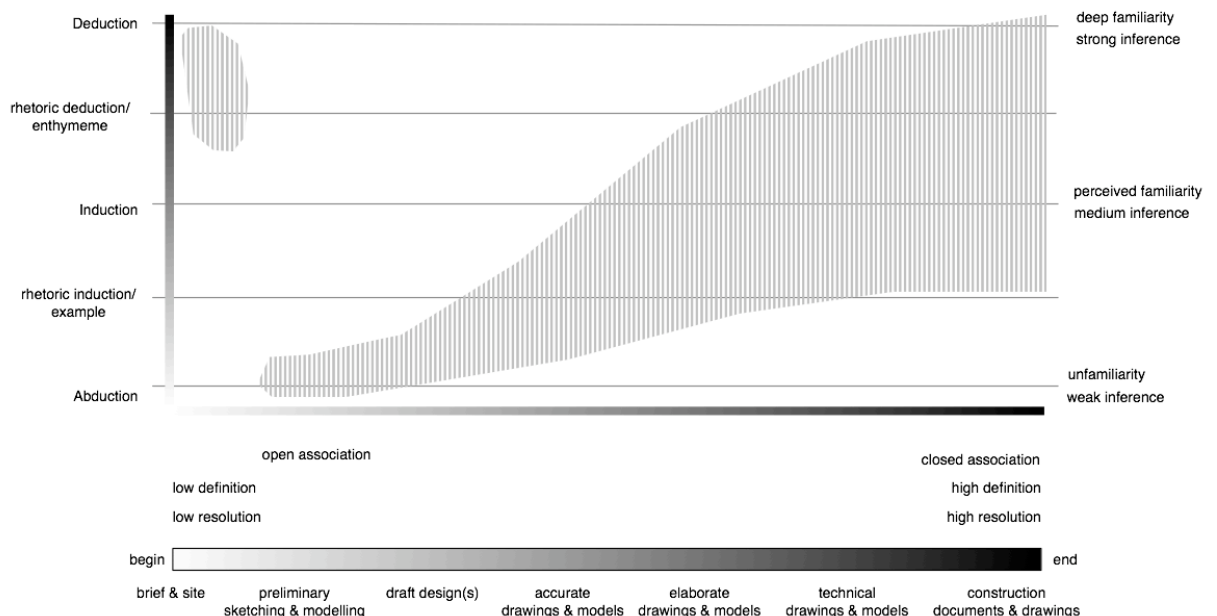


Figure 2.15: How the architectural design progresses through various phases of reasoning.

from facade details, to toilet solution, entrance typologies, a circulation scheme, construction principles, etc. The inductive reasoning becomes stronger because we have seen such particular sub-schemes, or sub-design-solutions many times before in drawings, and in the reality of built form, we can state with more confidence that a particular solution is not the right one, or that certain dimension are wrong, or that a door opens in the wrong direction according to necessary escape routes, etc. The design itself starts to establish an internal rationale, there are certain maxim's, rhetoric premises embedded in it, that need to be true otherwise the architect has nothing to base his reasoning on. In this way a certain sub-design-solution can make 'no-sense' in the sense that it doesn't fit what follows from the premises embedded in the design. In this way also certain 'good' solutions from an inductive point of view get into conflict with a deductions that follows from certain design premises. Such conflicts have to be negotiated, which result in compromise, ingenious solutions, or a sacrifice that has to be made on either side of the conflict.

2.3.3 The Core of Architectural Knowledge

While we know that individual architects and their practices bring certain knowledge to a project other practices can't, there is a core of architectural knowledge that is the same with all architects. In the sense that there needs to be certain knowledge present to be an architect in the first place. This has to do with the 'technologies' architects use, and the most dominant technologies are drawing and modelling. If we want in any way be more precise about how reasoning works within architecture, we have to address the medium through which reasoning in architecture is done. If we put it in terms of subject and object, the architect (subject) thinks with objects either imagined or real, on paper or in his mind's eye. Real or imagined objects are in essence the same, since the imagination works with the same memories as perception does. In Hawkins' terms the predictions of your brain are running through a circuit which guides them to an input again, something cortical modeler Stephen Grossberg calls "folded feedback" (Hawkins & Blakeslee, 2004)

The objects architects think with are not the same as mathematicians or writers (in general) they are drawings and models, they are images we can manipulate with our pen on paper, by cutting Styrofoam, and orbiting our 3D model. Such drawings and models, have a rationale of their own, they have their conventions, and limitations. The drawing has conventions such as elevation, section and plan, sketching the mass, volume or organisation of a building, but also how to draw what on a certain scale, putting arrows in the right direction to see if stairs go down or up. For models it is the same, we can cut foam, sculpture it, in a card board or wood model we put up the construction, in a 3D model mass doesn't exist, but we can extrude planes into objects etc. How we manipulate objects in the real world directly influences how we can use them in a form of reasoning and vice versa. Thus when we want to gain more detail about how we can understand some kind of reasoning as specifically architectural reasoning, and not any other kind of reasoning we need to understand the rationality that lies in the object we reason with. Peirce called the *rationale* that influences how we reason with objects "systems of representation", and how we reason with with these object "diagrammatic reasoning".

Chapter 3

The Diagrammatic Nature of Reasoning in Architecture

Architect themselves don't make buildings, they make drawings and models, they don't pile up bricks and bolt steel beams together. Robin Evans notes that this is "the peculiar disadvantage under which architects labor; never working directly with the object of their thought, always working at it through some intervening medium, almost always drawing, while painters and sculptors, who might spend some time working on preliminary sketches and maquettes, all ended up working on the thing it self" (Evans, 1995) Evans indicates the importance, of the 'medium in which the architect thinks' namely drawings and models. When Evans states that architects never work directly on the object of their thought, I am inclined to nuance this position. Because to what extend is an actual building the object of the architect's thought and to what extend are drawings and models of a building the object of the architect's thoughts. The answer would be that both are obviously, although this depends on the experience an architect has, how many building he has seen and how many of his own designs he has seen realised. The point I want to make is this one: that although drawings, models and buildings are object of thought that concern building, they deal with building in different ways, each has their own specific rationale. Working with a drawing gives you other insights than working with models, than going to the site or imagining how a space in the building would be experienced. What remains a fact is that one finishes the design of a building not yet realised. Only after the design is finalised the actual construction of the building commences. Although the architect is consulted during construction, he cannot on hindsight determine to do things differently. We could rephrase Evans' statement that the architect never works directly with the objectives of their thought, even when a project is never intended to be realised, the design is made according to the objective of a 'being a building'.

The technology which architects hold in their hands, are pens, pencils, paper, *Styrofoam*, wood, cardboard and material samples. The media over which their eyes move, are drawings, models, mock-ups and computer screens. All this technology is present in the everyday practice of architects, to develop ideas for themselves and to convey them to their peers, independent of if this is in a school or an office (see figure 3.1). In all this technology rules are embedded, in physical terms (*Styrofoam* is differently manipulated than paper), in terms of conventions (as in drawing), in practical terms (some technologies are fast, others slow) and in terms of aesthetics (materials evoke feelings, appreciation of beauty and taste). Not all rules are equally clear, or equally rigid or flexible. Most of the rules are implicit, we know them intuitively, and some of them are explicit, especially when drawings approach the end of the design process.



Figure 3.1: The objects of architectural thought consist of the mediating technologies architects work with in their design practice on a daily basis

All this technology plays a role in building up a representation of a building, a building not yet realised, or never to be realised. The architect in his drawings has a reflective conversation with the future, with ideas that haven't found the materials yet in which they will condense. These ideas are brought forward in the first scribbles that reach the paper, and develop into sketches of organisations and structures.

“For Peirce, all thinking took place with signs, things which served ‘to convey knowledge of some other thing’ which they were ‘said to stand for, or represent’. A sign therefore always was an object, and the sign in turn excites an idea in the mind, a mental sign of the same object, or that which interprets the sign.” (Vidler, 2006)

But what does Peirce mean when he talks about signs and object, these concepts will find their place within Peirce's theory of diagrammatic reasoning. Although Peirce developed the theory of diagrammatic reasoning within the context explaining creativity in mathematics (Hoffmann, 2006), its explanatory power is not confined to it, and the theory is described in terms that are general enough to enable a ‘transportation’ of Peirce's diagrammatic reasoning theory to other fields.

3.1 Pierceian Diagrams in Architecture

To understand what Peirce exactly means by diagrammatic reasoning it is necessary to know what he means with the word diagram. He defines it as follows: “a representamen which is predominantly an icon of relations and is aided to be so by conventions. Indices are also more or less used. It should be carried out upon a perfectly consistent system of representation, founded upon a simple and easily intelligible basic idea” (Peirce, CP 4.418, 1903) as cited by (Hoffmann, 2005)

In the diagram different characteristics of what Peirce calls signs converge. Peirce makes a distinction between three basic types of signs, namely: the index, the symbol and the icon.

[figure: archi examples of sign types: index=elevator floor number, icon= religious icon and symbol=cross on church]

- The function of the *index* is to direct attention towards something. “Pierce cites the barometer, that indicates the temperature, the weathervane that indicates the direction of the wind, or the polar star, from which we derive our sense of direction in nature” (Vidler, 2006)
- The *symbol* is sign with an established meaning based on convention. The relation between sign and what is signified is law-like, like traffic signs, national or religious symbols, letters and numbers.
- “An *icon* is defined as a sign that based on the ‘likeness’ to its object - ‘excites an idea naturally allied to the idea that object would excite’” (Peirce, EP II 13) as cited by (Hoffmann, 2005). So not only photos and footprints are icons but also for example, sentences and algebraic equations.

Peirce states that: “All our thinking is performed upon signs of some kind or other, either imagined or actually perceived. The best thinking (...) is done by experimenting in the imagination upon a diagram or other scheme, and it facilitates the thought to have it before one's eyes” (Hoffmann, 2005)

[figure: examples of diagrams: maths, language, mondriaan, ...etc]

The diagram is a subgroup of the icon, the difference as described above is that a diagram is an icon “carried out upon a perfectly consistent system of representation” (Hoffmann, 2005)

for example: “If we are confronted with (...) the complex sign ‘Theaeteus-Socrates-stands-sits-and,’ we could interpret this sign as an icon, because it represents a certain relation. But if we read ‘Theaetetus stands and Socrates sits,’ we have a diagram, because this sign represents a relation that is carried out upon our grammatical system of representation’ as defined by syntax.” (Hoffmann, 2005)

How can we classify architectural drawings and models when we use Peirce’s sign definitions, and does architecture have ‘perfectly consistent systems of representation’? For a construction drawing one could argue so, for a sketch this would become more difficult. Hoffmann nuances this position on consistency of systems of representation: “Nonetheless, even if representational systems are only partly consistent their rational and normative character is essential for what happens in the experiments we perform on diagrams.” (Hoffmann, 2005) Thus, what is essential is the rationale, and normative nature of a diagram and working with it. This opens up a wider interpretation of architectural drawing and model making.

3.1.1 Architectural Drawings as Pierceian diagrams

Drawing in architecture ranges from sketches to construction drawings, as described in the previous chapter, from the beginning to the end of the design process architectural drawings work from low definition towards high definition at the end. From more open association and speculative forms of reasoning, towards more closed association structures and deductive like reasoning. There are already rational and normative aspects in sketching, the sketch one is making always represents something concerning the structure, geometry or organisation of some kind of a project. A sketch usually works on a scale level, but not in an absolute sense. Whether an architect is sketching either a detail idea, a floor-plan, a perspective or an urban plan, drawings aren’t drawn in on an absolute scale on paper, the architect’s sense of scale when he is sketching is part of his appreciative system, as Schön calls it, it is implicitly present. When the drawing becomes more accurate, drawn to absolute scale, when symbols (in the Pierceian sense of the term) start emerging, the system of representation behind the drawing’s evolves more and more consistent. That is, consistent in an explicit manner, while systems of representation in the conceptual phases of design are largely hidden and implicit. The sketch is something a designer privately understands, but that often needs explanation to peers, the eventual construction drawings of a project, is something a whole professional community can read without the draftsman explaining to the contractor how the drawing should be read (ideally). This is why the final drawings of the design process also have legal power, because they can be interpreted independently.

3.1.2 Architectural Models as Pierceian Diagrams

The first distinction we have to make here is between digital models and real world models we can touch and hold in our hands. Besides the tactile experience the difference also lies very much in the model making experience itself. The digital model merges characteristics of drawing with modelling. Often one draws a digital model. When a series of lines close, ‘like a snake biting its tail’ a plane is created, a plane again can be extruded, and can again be manipulated in yet other ways. Also characteristics of real life modelling are present, there is a set of objects: cubes, cones, cylinders, spheres, etc. that are the materials for making a digital model. These objects can be manipulated in ways only a computer can, but also in the same way we do with a piece of *Styrofoam* for instance, cutting away pieces and sculpting an object.

The model’s representational system is different from that of the drawing. While a model can also deal with different aspects of a plan like structure, geometry and organisation, the ‘language’ is different. It is an actual ‘scaled down’ experience of space, a model isn’t limited to one plane

or perspective, it can be moved around, views can be changed, earlier ideas that were only worked out in drawing seem to work or emerge as problematic. The rational and normative aspects of models, don't directly lie so much in their representational nature, they are not limited to a 2D environment, they can like real buildings be perceived in a 3D environment (for real or through a screen). A model in this sense is one leap closer to buildings than a drawing is. A model speaks much more for itself, when we put a human figure in a model a layman can understand what he sees (although he will perceive different things the architect will perceive). The rational and normative aspects of the model lie directly in the used technologies themselves. One cannot extrude wood, but one can extrude 'pixels'. *Styrofoam* is cut, we remove what we don't need, but when using cardboard we get sheets, and put of the floors, facades, roofs and walls. This is why a certain material is also more useful on a certain scale. For an urban scale, *Styrofoam* is good, we don't need to see what is inside the building volume, for a 1:100 wood is better, since it can be worked with in more detail, it is stronger. Every material's rational and norms are embedded in the physical possibilities and limitations of a material, and the instruments one uses to work with them. In a digital model there is a very elaborate structure of rationality and norms present that are emerge directly from the software program it self. *AutoCad*, *Maya*, *3D Studio Max* and *SketchUp*, they all have their toolbars, model navigation and rendering possibilities, which in a very real way directly determine their embedded rationale. Although this system is very elaborately defined, it opens up infinite possibilities.

3.1.3 Reasoning with Models and Drawings

While we have explained the nature of models and drawings separately, in architectural practice we don't use these technologies separately. We cannot sketch on paper, and build a model at the same time. When we make a model we use drawings to build them and when we draw we examine our models to see how to revise and evolve a design, and in computer models we actually do both things at the same time. My point is that all the rationality's and norms that belong to individual technologies, be it a certain material, a certain computer program or your drawing style, in the design process they all mix, interchange, intertwine and contaminate each other. When the architect's mind continues designing, when he has left his pencils, computer and *X-Acto knife* on his desk, and continues thinking, imagining and reasoning, the mind isn't neatly keeping the various rationality's of associated technologies separate, they influence each other, they intricately connected. Thus in your mind you can 'extrude wood'.

3.2 Diagrammatic Reasoning

For Peirce the interaction of internal representations (in the mind) and external representations (in the world) in what he calls 'signs of some kind or other' is key.

This interaction is described in Peirce's concept of diagrammatic reasoning. Diagrammatic reasoning is based on the three step activity of "constructing representations, experimenting with them, and observing the results. The idea is that by representing a problem in a diagram, we can experiment with our own cognitive means, and thus develop them. 'The diagram becomes the something (non-ego) that stands up against our consciousness,' as Kathleen Hull puts it; 'reasoning unfolds when we inhibit the active side of our consciousness and allow things to act on us' (Hoffmann, 2005; Hull, 1994)

First we will look at the first two steps constructing representations and experimenting with them. "Any construction of a diagram is carried out by the means of a given representational system, and any experiment we perform on it is determined by the rules of that system. (...) Representational systems are more or less 'consistent,' ranging from axiomatic systems

in mathematics to the stylistic means of art (...) Nonetheless, even if representational systems are only partly consistent their rational and normative character is essential for what happens in the experiments we perform on diagrams.” (Hoffmann, 2005)

This rational and normative character of representational systems plays a paramount role in the third step of observing the results of experimenting within these representational systems. Peirce states that all reasonings “turn upon the idea that if one exerts certain kinds of volition, one will undergo in return certain compulsory perceptions. (...) certain lines of conduct will entail certain kinds of inevitable experiences” (Peirce, NEM I 122) as cited by (Hoffmann, 2005)

“Such an ‘inevitableness’ depends obviously on the given rules and conventions of the representational system in which such a reasoning is performed.” (Hoffmann, 2005) To experience something like this inevitableness it is necessary to have internalized a certain representational system, so one actually experiences the constraints of a that system. If this is the case one can feel inconsistencies, or one can be surprised about the results that experimentation generates. Very much like when we understand something or are initially confused when predictions are affirmed or violated in Hawkins’ theory or when the situation talks back, in Schön’s theory of reflection-in-action.

3.2.1 Similarities between Peirce’s Diagrammatic Reasoning and the models of Schön and Hawkins

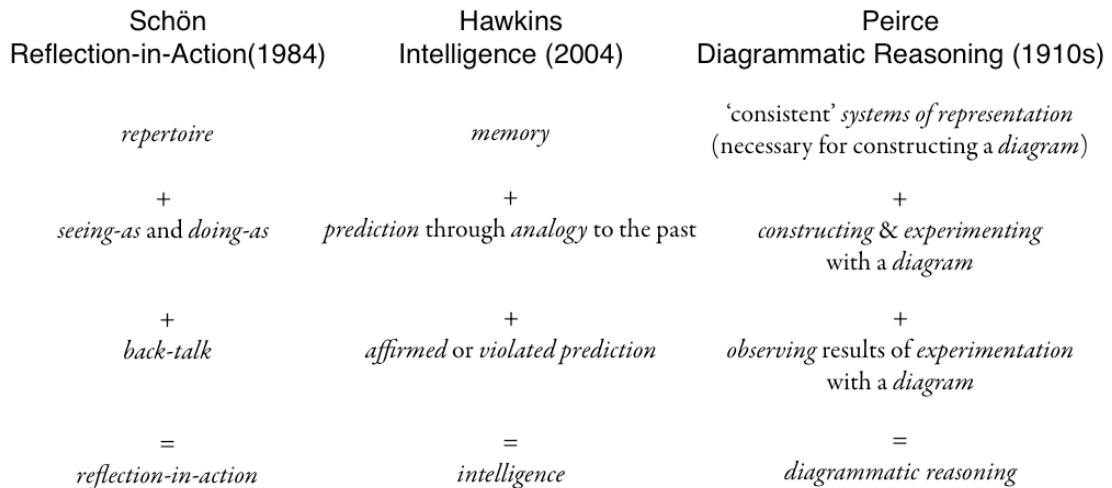


Figure 3.2: Similarities between theoretical notions in the work of Schön, Hawkins and Peirce

When we read this description of diagrammatic reasoning, we can observe more parallels between Peirce’s theory of diagrammatic reasoning and Schön’s theory of reflection-in-action and Hawkins’ theory of intelligence (see figure 3.2).

1. We can align Schön’s repertoire and appreciative system with Hawkins’ role of memory, with Peirce’s internalised representational systems. In all theoretical models they represent the same, namely our accumulated experiences, the knowledge we carry with us in our heads. From this knowledge we can write, draw and make diagrams (in Peirce’s terms: construct), based on the representational systems embedded in our knowledge.

2. Constructing and experimenting with diagrams can be aligned with Schön's seeing-as and doing-as, and Hawkins' prediction through analogy to the past. In all theoretical models, these operations are deeply dependent on existing knowledge and experience, the way they are dependent is twofold in the sense that firstly we bring our knowledge to bear on new and unique situations, but we do this through a search for similarity, likeness, to what we have seen, experience before. Secondly when we act upon these similarities, we also do this in analogy, action is not random but more or less guided by the structures and systems we have internalised. What we do and how we appreciate it, is dependent on these systems.
3. Finally we can also align Schön's back-talk, Hawkins' affirmation or violation of prediction with Peirce's observing the results of experimentation with diagrams. When we experiment within certain system of representation, we make (unaware and unarticulated) predictions about what our experiments will result in. If these expectations are violated, in other words if we encounter inconsistencies, resistance or accidental results, we will take notice, and can act upon such an observation. Or as Hawkins says "Correct predictions result in understanding. (...) Incorrect predictions result in confusion and prompt you to pay attention" (Hawkins & Blakeslee, 2004). The consistency of a system of representation we work with, or the degree to which we have internalized it, influences our capacity to do predictions within it. This last phase of diagrammatic reasoning has consequences for the system of representation, in the same way as in Schön's model back-talk can lead to adjustment of one's appreciative system. The mechanisms that are at work in how we reconsider our appreciative systems that lead to the eventual revisions or even 'new' systems of representation Peirce specifies with the terms hypostatic abstraction and theoric transformation.

One might wonder where Peirce's term abduction would fit in here, strangely enough there are hardly any writings found of Peirce where he discusses both. (Hoffmann, 2006) But Hoffmann argues that diagrammatic reasoning is at least a facilitation of abduction (Hoffmann, 2006), especially the last phase where one is unfolding new implications of existing representational systems, or where one is involved in developing new representational systems.

3.3 Finding 'Something New' in Architecture Through Developing Systems of Representation

It is necessary to make some distinctions in how Hoffmann explains Peirce's diagrammatic reasoning and how it would be usefully transported to reasoning in architectural design. Hoffmann explains diagrammatic reasoning in the context of mathematics and this is also the context in which Peirce himself developed his theory. This is problematic to a certain degree; although some concepts are indeed useful and deliver additional insight, but the steps through which we find 'something new' with diagrammatic reasoning are different. How these steps unfold in mathematics do not fit the nature of the design process in architecture.

Something new can be found in two fashions as described:

1. One being the unfolding of *new implications* of an existing representational system.
2. The other being the development of *new representational systems*.

A general difference of finding something new within design or within mathematics is the point of departure. In mathematics one has an extremely well defined axiomatic system which can be

brought to concrete situations. Capturing a situation mathematically is a craft in its own and at the mathematicians disposal is an extremely well consistent axiomatic system of representation. The first step would be to capture the situation within the existing mathematical system of representation. In doing this, new implications before not thought of can unfold. Only when the existing body of mathematical knowledge cannot deal properly deal with a situation, the second step comes into view: developing new representations, in other words new axioms.

In architectural design, there is little defined at the start of the design process. There is an enormous body of architectural knowledge at the architect's disposal, but most importantly this knowledge is not axiomatic in any way. The premises in architectural are hardly ever axiomatic, because then logical deduction would suffice. As shown in chapter two, reasoning in architecture is much more rhetorical in nature; architects pose maxim's not axioms. An axiom would imply that throughout the architectural discipline everybody would agree on the something and this is hardly the case. The only system in architecture is axiomatic in nature are the final construction drawings, the blue-prints of the final design, which will be used for construction. Here there is also a need for axioms, the construction drawing has to be understood by the entire building industry, there is a necessity to agree on the system of representation. An architect doesn't start the design process with drawing a building according to the conventions of the construction drawing.

Architectural design is continuously involved with the 'unfolding new implications' but not within axiomatic systems. Rather the concepts Peirce describes under the header of 'developing new representations' are a more fitting description of what the architect does in the design process.

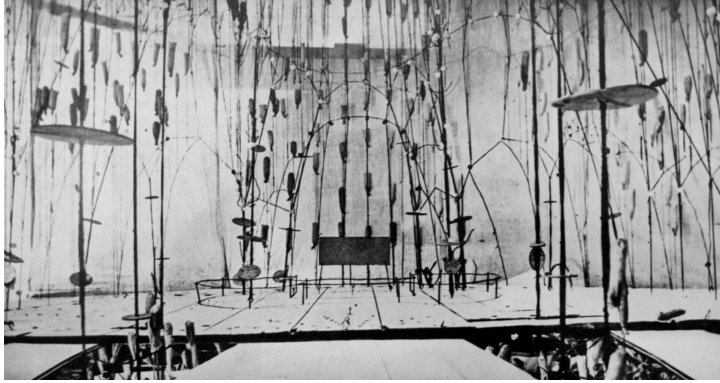
3.3.1 Developing Systems of Representation

One of the ways representational systems in architecture innovate has a lot to do with the role various technologies and their embedded rationality's play in the architectural design process. New technologies in architecture are sometimes originated by architects and in other cases adopted from other fields. The hanging chain models of Antonio Gaudi would be an example of the first and the adoption of the Maya software package that was originally developed for the film and game industry is an example of the second. Architects originate or adopt new representational systems not necessarily because another systems of representation hinder them, but more from an pragmatic or opportunistic motivation. New technologies can be potential generators of new forms, result in faster drawing production or produce more compelling imagery.

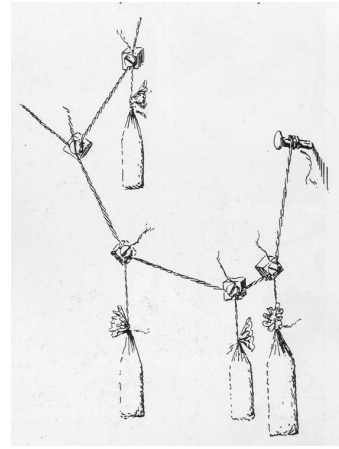
New representational systems are added to the collective body of architectural knowledge over the course of history, some of them become part of the repertoire of individual architects depending on the schools they went and offices they practised. While these new technologies heavily influence the architectural design process there is still a need to construct a specific rationality for each individual project. These premises for a project will not automatically follow from a certain technology, i.e. system of representation, that is used. Although every technology has it's own premises embedded that imposes certain limits, but this doesn't make the architect a servant of technology, rather the contrary.

3.3.2 “The highest kind of synthesis”

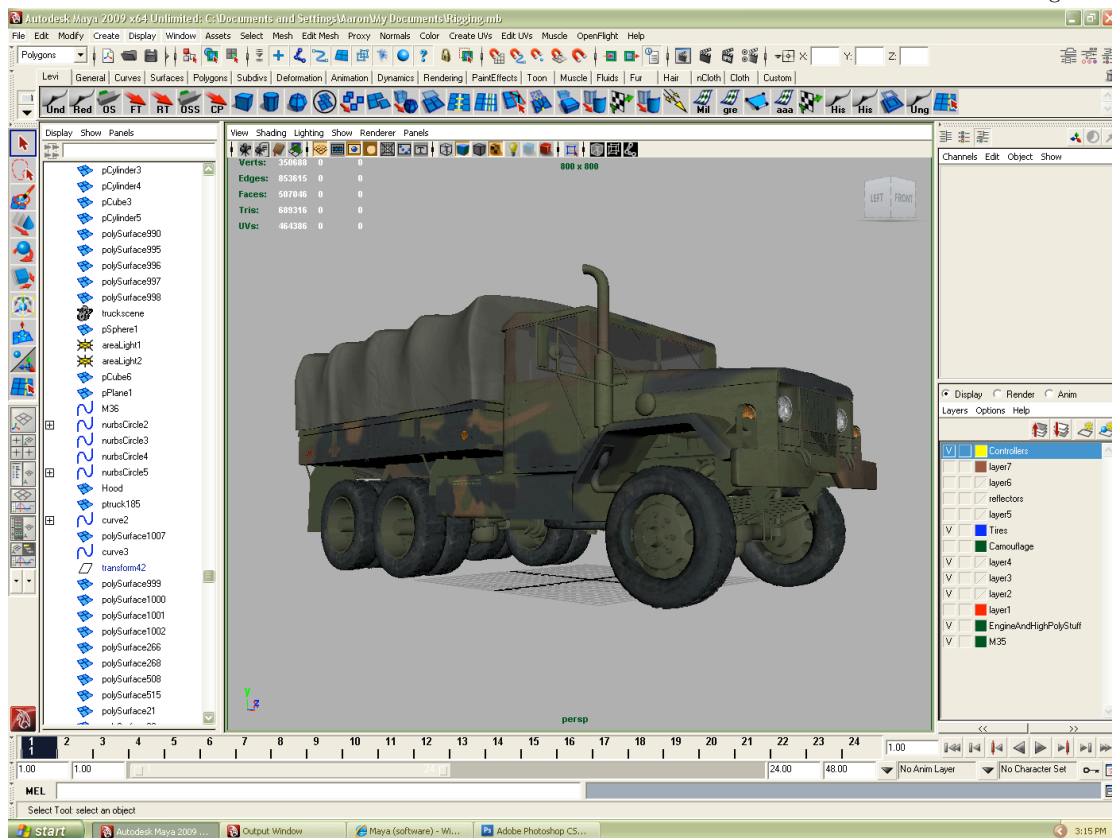
Especially under the heading of developing new representational systems, Peirce introduces some notions that elaborate on how we could understand abductive characteristics in his theory on diagrammatic reasoning. “Peirce called this ‘the highest kind of synthesis,’ when the mind - ‘in the interest of intelligibility’ - introduces ‘an idea not contained in the data, which gives



(a) One of Gaudi's catenary (hanging chain) models (the photograph is upside down)



(b) A detail of Gaudi's catenary model, by adjusting and moving the weights the curvature of the chain or wire could be changed



(c) A screenshot of Maya 3D modeling software

connections which they would not otherwise have had.’ He compares such acts of synthesizing with the creativity of an artist:” (Hoffmann, 2005)

“The work of the poet or novelist is not so utterly different from that of the scientific man. The artist introduces a fiction; but it is not an arbitrary one; it exhibits affinities to which the mind accords a certain approval in pronouncing them beautiful, which if it is not exactly the same as saying that the synthesis is true, is something of the same general kind. The geometer draws a diagram, which if not exactly a fiction, is at least a creation, and by means of observation of that diagram he is able to synthesize and show relations between elements which before seemed to have no necessary connection. The realities compel us to put some things into very close relation and others less so, in a highly complicated, and in to sense itself unintelligible manner; but it is the genius of the mind, that takes up all these hints of sense, adds immensely to them, makes them precise, and shows them in intelligible form in the intuitions of space and time. Intuition is the regarding of the abstract in a concrete form, by realistic hypostatization of relations; that is the one sole method of valuable thought”

(CP 1.383, 1888) as cited by (Hoffmann, 2005)

From this citation of Peirce we can abstract a three step description of the process that is fundamental in the development of systems of representation. For an architectural illustration of this see Louis I. Kahn’s traffic study in figure 3.3.

1. Observing something abstract:

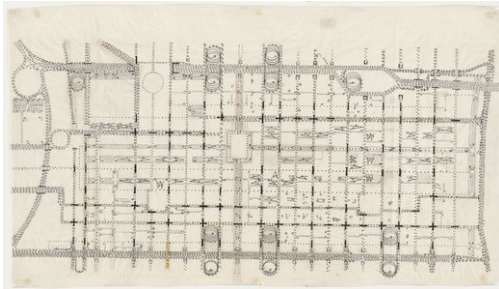
First something abstract has to be observed in a situation, unnoticed relations between elements have to be noticed. This is also described in section LABEL on abduction as an analogical operation, as perceive similarity between elements in a situation through a shared abstraction, or in Hawkins’ terms an ‘invariant representation’.

2. Generating a new object of thought:

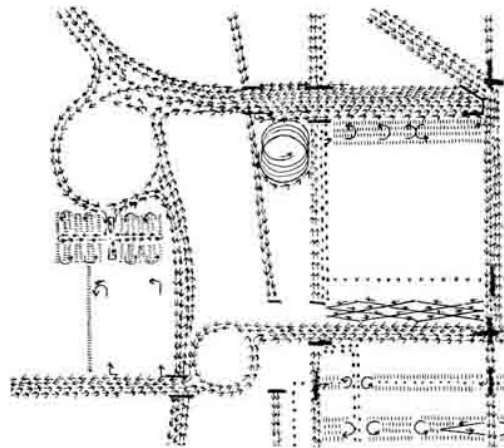
The introduction of a fiction is the act that constitutes the second step. The introduction of a fiction constitutes the act ‘to synthesize.’ “The central point of constructing diagrams and experimenting with them is that these are the only activities through which we gain ‘elements’ and ‘relations’ to observe. We need something before our eyes in order to discover something ‘new’ in the constructions of what we already presume to know.” This is why ‘hypostatization’ is needed, or the “regarding of the abstract in a concrete form” With the construction of a diagram one makes an object that will signify the characteristics that have been abstracted from the specific. This is what ‘hypostatization’ or in other words ‘reification’ can be understood as; “creating a thing out of what is not a thing; an entity out of an abstraction” (see figure 3.4) This is a process that leads to new objects of representation, a process of generating objects we can think with.

3. Intelligibility of the generated object in the situation:

Only when we introduce these new objects of representation again in the situation, we can abstract again, and see if they work or not, this constitutes the third step where we have to see if the two previous steps have lead to a “intelligible form” or in other words: Can we say that the synthesis is true? Is the introduced fiction intelligible? Observing if the introduction of elements into a situation results in intelligibility or



(a) Traffic study for Philadelphia by Louis I. Kahn, 1952 (courtesy MOMA)



(b) A detail of Kahn's traffic study

Figure 3.3: Kahn's traffic analysis is a good example of the development of a system of representation. He observed something abstract namely the characteristic of traffic movement, for this he generated a notational system "The drawing's abstract notational system corresponds to different tempos of traffic, such as the stop-and-go movement of trucks and buses (dotted lines), the fast flow of vehicles around the periphery (arrows), and the stasis of cars in parking garages (spirals)." The creation of these objects representing the flow of traffic also produces intelligibility for Kahn beyond the mere representation of traffic movement. "To explain his movement study, Kahn invoked a historical analogy: for him, the girdle of expressways and parking towers circling the city center metaphorically recalled the walls and towers that protected the medieval cities of Europe. Kahn's specific comparison was to the largely medieval town of Carcassonne, in the South of France: just as Carcassonne was a city built for defense, Kahn envisioned the modern city center having to defend itself against the automobile."

(Reed, 2007)

not takes place as part of the process of what Schön describes as when: a situation talks back in the reflective conversation the architect has with it. How the back-talk is judged depends on how the situation is appreciated by the architect.

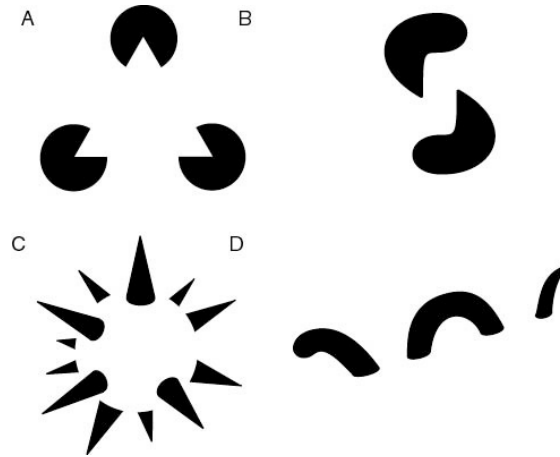


Figure 3.4: An example of reification from Gestalt psychology. A triangle will be perceived in picture *A*, although no triangle has actually been drawn. In pictures *B* and *D* the eye will recognize disparate shapes as ‘belonging’ to a single shape, in *C* a complete three-dimensional shape is seen, where in actuality no such thing is drawn.

Hypostatic abstraction

The crucial process that is done above with respect to adding new object to systems of representation, thus developing them is in step two, the step of reification, or hypostatic abstraction as Peirce calls it.

“Whatever we discover or learn as something ‘new’ can become a subject of our considerations only in the form of ‘hypostatic abstraction’ (...) In the operation of hypostatic abstraction we generate new signs signifying objects that were never mentioned before as object. Thus, all concepts in our language are outcomes of hypostatic abstraction performed at some time in the long history of our cultures. When we teach our children concepts, we usually try to give them opportunities to repeat this creative operation of hypostatic abstraction; they discover the world by generating their own hypostatic abstractions out of experiences and observations for which they did not have adequate concept before. (...) The most important point of hypostatic abstraction is that a sign is generated as a new object, and as referring to a new object, can be used, in turn, as a means for further operations also in different contexts. (...) These new objects -as ‘independent’ from the subject’s activity- are the starting point for further hypostatic abstractions, so that we gain a process that can be grasped as a process of generalizing our representational means.”

(Hoffmann, 2005)

Hawkins explains how the same process works but than in terms of the brain build up new knowledge, or expertise as he calls it.

“A young brain is slower to recognize inputs and slower to make motor commands because the memories used in these tasks are higher up the cortical hierarchy. Information has to flow all the way up and down, maybe with multiple passes, to resolve conflicts. It takes time for neural signals to travel up and down the cortical hierarchy. A young brain also has not yet formed complex sequences at the top and therefore cannot recognize and playback complex patterns. A young brain cannot understand the higher-order structure of the world. Compared to an adult’s, a child’s language is simple, his music is simple. and his social interactions are simple.

If you study a particular set of objects over and over, your cortex re-forms memory representations for those objects down the hierarchy. This frees up the top for learning more subtle, more complex relationships. According to the theory, this is what makes an expert.(...)

Experts and geniuses have brains that see structure of structure and patterns of patterns beyond what others do. You can become expert by practice, but there certainly is a genetic component to talent and genius too.”

(Hawkins & Blakeslee, 2004)

Expertise is fundamental in the generation of new knowledge, the generation of new ‘objects’ that are generalised from our own subjective hypostatic abstractions, and in that way enter the public domain of knowledge. In architecture hypostatic abstraction plays an important role in every design project, in the sense that in the early stages of the design we need to turn a brief into a form, we have to recognise abstract order, and invent an object from that abstraction, in other words a design.

For instance when we look at the Seattle Central Library project, one of the hypostatical abstractions that was made is to recognise and thus abstract from the program as given: predictable and unpredictable programmatic elements. Recognising this was based on experiences with other libraries they had seen before, organised according to high-modernist flexible ideas. High-modernist flexibility treats predictable and unpredictable program equally and causes problems in that one type of program engulfs more vulnerable types of program, such as the social function of the library. The diagram generated to represent this abstract notion is capable of telling this story, thus it is an intelligible object. Because the object is intelligible it functions as an object, a maxim if you will, for further reasoning in the design process, as has been shown in chapter two.

Theoric transformation

Another notion Peirce introduces which relates to ‘introducing an idea that is not contained in the data’ is not so much about making an object out of something abstract, as in hypostatic abstraction, but is more about reading the same object different. What one actually does is perceiving an object but changing the rules that govern it, and thus making oneself able to read the same object differently. What one actually does is replacing the system of representation that lies behind the object one perceives and thus one changes the rules of how one can reason with it. In simpler terms, one changes from perspective, how one perceives something.

When Ben van Berkel talks about his work one can recognise this mode of reasoning.

“The same image may be just a picture to you and a diagram to me. The difference would be that for you it would represent an inspirational idea and to me a suggestive, instrumental and experimental direction, with a possible spatial organisation and /or substance”

(Berkel, 1998)

and

“When we refer to diagrams we do not tend to concentrate so much on the notational technique, as on the interpretation of the diagram. There is a big difference there, in that we use the diagram for organisational research. We have also used a Chinese character as a diagram for the organisation of the Schloss project in Berlin. In the way we used it the sign is an abstract form, devoid of any significance. We never even looked up the meaning of the sign.”

(Berkel, 1998)

Hoffmann explains it as follows “Theoric transformations are the key elements in all kinds of creative reasoning. New ideas do not emerge from nowhere in our minds, nor can we generate them out of nothing in acts of pure contemplation.” (Hoffmann, 2005) or as Hawkins says “Creativity is mixing and matching patterns of everything you’ve ever experienced or come to know in your lifetime. It’s saying ‘this is kinda like that.’ The neural mechanism for doing this is everywhere in the cortex.” (Hawkins & Blakeslee, 2004)

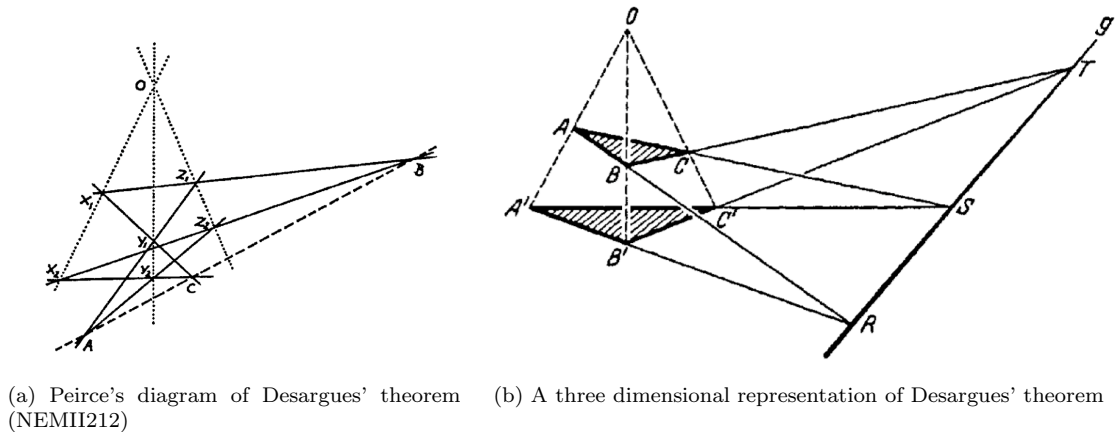


Figure 3.5

The example Peirce himself uses to illustrate theoric transformation is Desargues' theorem.

“As an example, he (Peirce) often hints at the famous proof of Desargues' theorem about two triangles in a projection. According to Figure ..., the theorem can be formulated as follows: Given two triangles $X_1Y_1Z_1$ and $X_2Y_2Z_2$, if the straight lines X_1X_2 , Y_1Y_2 and Z_1Z_2 meet in O , then the intersection points C of X_1Y_1 and X_2Y_2 , B of X_1Z_1 and X_2Z_2 , and A of Z_1Y_1 and Z_2Y_2 lie on the same line ABC . It seems to be remarkable that these points belong to the same line, but if you change the point of view, and perceive the triangles as planes intersecting a pyramid with O as apex, then the situation is quite clear, as Figure shows. At least in an intuitive manner, Desargues' theorem can be proved easily by saying that any two planes in

space intersect in a line (in the case of parallel planes, the situation is different, of course).”

(Hoffmann, 2005)

The critical step, the theoric transformation that is made in this proof of Desargues’ theorem, is as Peirce explains to see the problem as a projection of three dimensional space. Thus reading the same object, but perceiving another system of representation behind it.

Also in the Seattle Central Library project a theoric move is made when the program analysis is done through a sequence of bar diagrams, each representing the square footage subdivided under different thematic headers (see figure 3.6a). Then in the last bar diagram (on the right), instead of reading the diagram as a two dimensional graphic representation of program, the diagram is read as the section of the library. Here a theoric transformation is present. The initial function of the bar diagram is to show quantity (size) and types (colour) of library program. In the bar diagram the size of the various coloured patches are proportional to the square footage of floor space each type of program needs. The bar on the far right is read as section as well as floor plan. The coloured patches are easily read as floor-plan since the patches already represent floor space, but reading the combed bar as a section constructs the leap to the eventual architectural form of the library (see figure 3.6c and 3.6b).

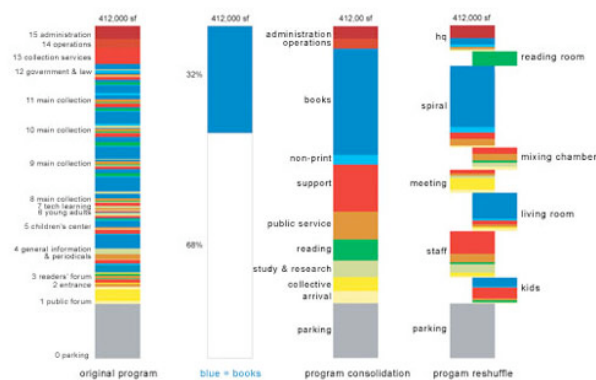
3.4 Concluding: Routes for Peirce in Architecture

There are many things not written yet that could be said about the matters that were dealt with in this project, but this research should open up new ways of analysing the work and thought of architects, mainly through their tools in the design process. Models and drawings, and the knives and pencils they are made with. While the effort has been made to properly illustrate arguments in this writing project with architectural examples, many more examples need to be found, to support the broad application or expose the limitations of the concepts put forward.

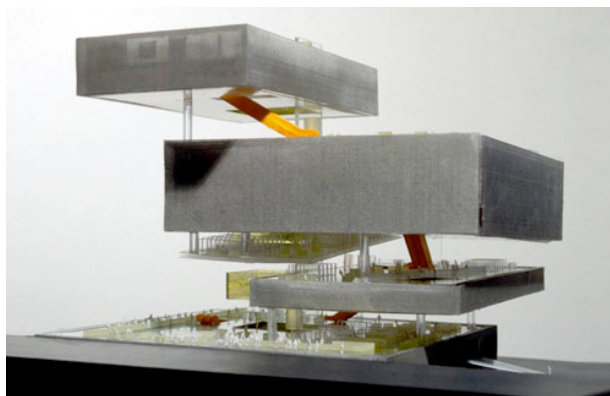
With Peirce’s notion of diagrammatic reasoning an entire re-reading of architectural history, and the architectural body of knowledge in general opens up.

Behind architectural drawings and models the systems of representation have developed over history, moving from the symbolic proportional system of the renaissance, its structured form according to the proportions of man and the cosmos, to objective unitary measurement systems and descriptive geometry that were introduced during the enlightenment.

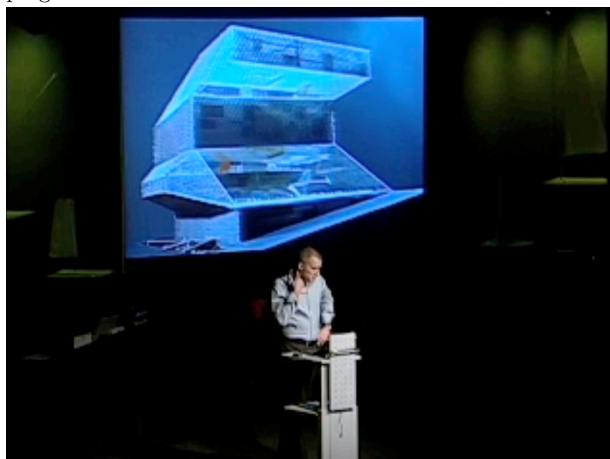
Contemporary architecture went beyond the arguments of rationality and efficiency (although much of the contemporary building industry dominated by this rationale) and became fascinated with adopting other systems and how they could generate form. Through mapping the contemporary conditions of our society many architects found new conditions that could be read as systems of representation and informed the projects they were designing (as illustrated with Ben van Berkel’s citation). Program is the main driver of form in many projects in one way or another. Flows of data, real or imagined form malleable shapes in 3D computer environments, which result in ‘blob’ buildings. Others unleash statistical calculations on all kinds of data and create so called ‘datascares.’ In all these and much more practices (contemporary and historic) it would be very insightful to analyse what kind of hypostatic abstractions have been made, and which theoric transformations have been performed in working with certain systems of representation.



(a) From the program analysis on the left to the first outlines of architectural form on the left. Blocks shifted to the right are the unpredictable program elements, to the left the predictable ones



(b) The model of the Seattle Central Library without its facade, the closed volumes contain the 'predictable' program elements, on the 'roof tops' of these element the 'unpredictable' program is realised



(c) Joshua Prince-Ramus presenting the Seattle Central Library at TED. Behind him the final design is projected.

Figure 3.6

Following the route of utilising Peirce's theories to analyse architectural production is one way of obtaining deeper insight in what over the course of history has been the main drivers of architectural thought and how architectural reasoning itself developed over many centuries. Another route is researching more of Peirce's theory more thoroughly and determining to what extend concepts are fitting in explaining architectural thought and reasoning. One aspect Hoffmann is researching more closely which would be of interest, is how we can understand in more detail how abduction relates to concepts in the diagrammatic reasoning. When we could consolidate both this could result in a theory of reasoning that to a greater degree gives acknowledges to various types of reasoning and how they are inter-connected. From deduction on one end of the spectrum and abduction on the other, joined in one theoretical framework explaining how reasoning with signs works, from the axiomatic systems of mathematics, to the fluid shifts of meaning behind the signs architects think with.

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Besides these references I would like to refer to <http://wikipedia.org>, while I can't list it as a specific source, it helped me immensely in navigating an ocean of knowledge, for which I would express my gratitude to the *Wikipedia community* for directing me to relevant ideas, names and sources