

Can IT bridge the Gulf between Science and Architecture?

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The integration of technology into design work has always been seen as one of the serious problems in design education. In architecture the weak integration between architectural science, a subject based on objective knowledge, and artistic design which is based on tacit knowledge and creativity is a problem that has been debated to great length, and an issue of great importance to both academics and professionals. This paper raises the question: can a proper use of IT, both as a design tool and/or as a performance analysis tool, foster better integration and strengthen design quality?

This paper investigates the relationship between Science, Design and Computer Aided Design. It aims to both highlight the problems facing the integration between architectural science and design, and describe a framework within which they can be analysed. The paper critically examines the following:

a) The perceived gulf between science and design

b) The parallels between hypothesis in design and hypothesis in science

c) The basis of architectural design: intuition or research?

d) Architectural Science and Computer Aided Design (CAD) and the role they can play into bringing about a marriage between science and design. The paper concludes by developing a conceptual framework that can be used as a vehicle to build a CAD system for use during the design process.

Introduction: Science and Architecture

This section examines the origins of science and the structure of the scientific method in an attempt to assess the impact of both on the development of professional knowledge such as design. Knowledge can be classified into two categories: *science-based (and/or technical rationality)*, and *professional*. Design has always been considered part of professional knowledge to distinguish it from *fine art*, i.e. painting.

Literature reviews on science and architecture reveal that there have always been reasons to base design in architecture on models of science. One such reason might be that a science-based architecture could help in solving the problem of the 'battle of styles'. Another reason could be related to the desire of professional knowledge to attain higher levels of academic rigour and status by conforming to paradigms of basic science. For example, Brawne (1995) likened the design hypothesis to Popper's scientific hypothesis,

P₁ then TS then EE then P₂

where, P_1 is the initial problem (design problem), TS is a tentative solution to it (design hypothesis), EE is the process of error elimination, of testing P_2 which is the final solution in one sense and a new problem in another.

Semper, whose influence on the Bauhaus was immense, expressed the above process in a mathematical form when he introduced the formula: $Y = F(x, y, z, \dots, n)$, where, $Y =$ the end result, $F =$ a functional relationship, $x, y, z, \dots, n =$ different forces acting together.

Durand and Palladio's attempt to confirm that architectural knowledge can be made objective by defining methods for creating buildings was another step into the scientification of architecture. (Madrazo 1994) Influenced by Linnaeus's work on the classification of species, Durand argued that architecture can be made more objective by subjecting it to a process of classification and systemisation. He embarked on a comprehensive work to classify buildings into two major groups: historical (Egyptian temples, Roman palaces, etc.) and functional (theatres, hospitals, etc.)

Suggestions of a linkage between architecture and other scientific disciplines in the form of analogies have surfaced in the literature. While mathematical analogies hold that numbers and geometry provide an important basis for problem solving in architecture, organic analogies on the other hand, view the building as a biological process rather than aesthetic (Collins 1966). It could be argued that the origin of certain architectural phrases such as 'Form follows Function' is biological. Steadman's book (1979) on 'The Evolution of Designs' is a comprehensive review of the analogies that have been made since the end of the 18th Century between biology and architecture. Such analogies were classified under four headings: a) 'the classificatory analogy'- categorisation methods borrowed from zoology and applied to the history of architecture; b) 'the ecological analogy'- the appropriateness of designed objects for their functional purposes as being similar to the fitness of organisms to their environment; c) 'the Darwinian analogy'- trial and error in the development of artifacts and organisms; d) 'the anatomical analogy'- the correlation of parts between structures and animal skeleton.

In a paper entitled 'Architectural Science in Retreat?', Stevens (1988) stressed that architecture's attitude to science has gone through a number of facets since science crystallised and became a social institution in the 18th century. He successfully identified two 'coherent' and polemic positions towards science. The first attitude, the romantic tradition, was that of Ruskin and Morris which was anti-science as it rejected technology and industrialisation, and by implication science. This dictum was criticised by Heath (1984, pp 36-37) for being too abstract and praised for encouraging the individual freedom of expression. The second attitude was cultured by the Modern Movement which called for the adaptation of science and technology for the benefits of architecture.

Science and Design

i) Science, Knowledge Acquisition, and the Scientific Method

Several architectural theoreticians have argued that the scientific method has always had a significant impact on the development of design knowledge, design philosophy, and the design process. For example, March claims that Popper's philosophy on 'deduction' and his doctrine on 'falsifiability' has had an influence on modern architectural design theory. (March 1976) Therefore, it is both imperative and critical for this paper to review both the scientific method and knowledge acquisition techniques.

Western intellectuals have always held an exalted view of science as being based on a justified true belief. Science, regarded by some as a paradigm for what other types of knowledge ought to be, is that body of knowledge which can be made into a system, and which usually depends on seeing and testing facts, and stating general natural laws. This means that observation is foundational in and fundamental to science, and theories are generated from evidence.

Dewey (1966) regarded science as an 'authorised conviction' and argued that 'without initiation into the scientific spirit one is not in possession of the best tools which humanity has so far devised for effectively directed reflection'. Plato held a contrasting view to Dewey as he thought of science as inferior to philosophy and mathematics because it relied on observation and as such changing dimensions of self-experience. (Phillips 1987) However, he was not speaking of science from an epistemological viewpoint, i.e. how to acquire knowledge.

There are two conflicting ways of looking at the world regarding knowledge acquisition: the 'romantic' and the 'classic'. Both views seek objective truth and reject relativism, sophistry and rhetoric. The romantic view, linked to Socrates and Plato, suggested that knowledge can be obtained through intuition and experience. Such a method is the norm in inspirational and creative arts and sometimes architecture. The classic view, linked to Aristotle and

adopted in science and architectural research held that knowledge can be acquired by the study of underlying form and structure using laws and reason. (Pirsig 1975)

Van Dalen (1979) classified methods of obtaining knowledge into old and new. The old method includes authority, tradition and culture, church and ancient scholars, personal experience, and expert opinion, deduction, and induction (perfect and imperfect). A deductive argument, sometimes called Aristotle's 'syllogism', consists of three propositions. The first two statements are called 'premises' which provide the evidence for the 'conclusion', the third statement. The modern method of acquiring knowledge, sometimes called the '*scientific method*', combines inductive and deductive thought processes to engage in reflective thinking. Induction provides the foundation for hypotheses formulation, and deduction explores the logical consequences of hypotheses to eliminate those not in harmony with the facts before induction is used again to confirm the hypothesis.

The scientific method has generated a logic of justification/confirmation which was severely criticised by Popper (1972) who stressed that 'scientific knowledge claims can never be fully proven or fully justified, they can only be refuted'. This marked a turning point in the history of science, its epistemological basis, and the scientific method. So it is the refutation of a hypothesis rather than confirmation our knowledge should seek, according to Popper. This means that scientists and researchers should adopt a critical attitude rather than a dogmatic one; they should formulate conjectures and subject them to criticism with falsification as the aim.

Johnson(1983), in the History of the Modern World, wrote that it was Einstein's exercise in scientific verification that impressed and influenced Popper's intellectual development most. The great scientist was searching for crucial experiments whose agreement with his predictions would not fully confirm his theory, while a disagreement, as he was the first to emphasise, would fully refute it. This scientific attitude was completely different from Marx, Freud and Adler who would always look for experiments to agree with their predictions and confirm their theories. To attain higher levels of rigour and objectivity, would it be possible to base architectural research on Einstein's model of refutation through crucial statements and/or experiments?

Popper's problem, it is argued, was his inclination to underestimate even the most significant achievements of the social sciences unless they agreed with his methodological model (problem identification, hypothesis formulation, and hypothesis test), a condition which they did not meet. Social science did not fall under his category of the best version of science which he called 'Great Science', i.e. Physics. (Mokrzycki 1983)

ii) Deduction and Induction in Science and Design

Design models often rely on deductive and/or inductive reasoning to describe the design process. This section, therefore, will attempt to explain the conceptional and the operational definitions of ideas that relate to both forms of logical analysis (Logic deals with arguments and inferences in order to distinguish those which are logically correct from those which are not). (Salmon 1963)

Deductive arguments are 'valid' when the premises are related to the conclusion in such a way that the conclusion must be 'true' if the premises are true. Validity is a property of arguments whereas truth is the property of individual statement. Deductive arguments are designed to establish conclusions whose content does not go beyond the content of the premises. Inductive arguments, on the other hand, postulate that if all the premises are true, the conclusion is probably true but not necessarily true. This is the case for the conclusion of an inductive argument containing information not present in the premises.

When they encounter problems, scientists and designers often indulge in the act of reflective thinking and use both deduction and induction. In 1910, Dewey in 'How We Think' outlined the stages involved in the act of problem solving (Dewey 1933):

- a. A felt difficulty: one encounters a puzzling obstacle [*a design problem*].
- b. Location and definition of the difficulty through observations and data collection. [This is induction, i.e. searching for a rule or a design aid. This is similar to an architect extrapolating user requirements from the brief. The search for a rule resembles the architect's search for a design precedent. Broadbent's 'iconic', 'analogic' and 'canonic' designs are all descriptions of a design by formal pictures. (Broadbent 1973)]. *CAD based databases can help in retrieving architectural icons quickly and frequently.*
- c. Suggested conjectural solutions of the problem- hypotheses. [During the cognitive process of designing, architects make a series of inductions until they arrive at a 3D form that best matches the brief. Alexander's synthesis of 'form' that matches the 'context' is an attempt to define form as a design 'hypothesis'. (Alexander 1966)] *Quick modelling CAD tools can help the architect's cognitive system to formulate a design hypothesis.*

d. Application of deductive reasoning to determine the consequences of suggested solutions. [The designer evaluates the proposed hypothesis/design solution. Forms of evaluation include environmental, structural, functional, behavioural, socio-cultural, aesthetical, etc.]. *Performance analysis CAD based tools can help quicken the process of design performance prediction and evaluation.*

e. Testing the hypothesis by action. [This amounts to the evaluation of designs as in d, or/and the appraisal of real buildings in use. Here one searches for a rule (induction) and applies the rule to the building (deduction).] *IT tools and techniques, including processor based monitoring loggers, can provide some objective tests.*

The above framework of problem solving has influenced a number of scholars in their bid to generate descriptions of design. For example, Broadbent (1969), in his 'design method', has introduced a conventional description of design. He argues that the 'composition' of a design solution is created from the 'decomposition' of the design problem, i.e., analysis-synthesis model. An alternative model of the design process, the conjecture-analysis, suggests that a design problem can only be realised within the context of a design solution. (Hillier et al. 1972) This means that a design solution is allowed to exist at a much earlier stage than the analysis-synthesis model. Also whether the design process is systematic or not depends very much on how the designer prestructures the problem.

In an attempt to distinguish between science and design, March (1976) put forward the statement: 'Logic has interests in abstract forms. Science investigates extant forms. Design initiates novel forms'. His investigation of design methods has led to a very elaborated design model called the P.D.I (Production, deduction and induction) framework. Production is the inference of a case from the rule (composition). Deduction is the application of a general rule to a case (decomposition/evaluation). Induction is the inference of the rule from the case (supposition). The reiteration of the P.D.I model within (horizontal) and between (vertical) each stage of the design process will eventually refine design until it is completed. The process is outlined below:

(P₁D₁I₁ P₂D₂I₂ P₃D₃I₃ )

The systemisation of the design process in line with the general structure of problem solving which involves the use of 'rules' and 'inferences', though criticised by many, has enabled the creation of a number of ambitious software packages during the 1970s. These packages focused on the realisation of a design using simplified 3D modelling. Examples include OXSYS and HARNESS for the strategic planning and design of complex buildings, mainly hospitals, and CEDAR for the design of school buildings. (Richens 1992)

iii) Design and Creativity

Design is the distilled essence of the discipline of architecture. However there is also a great deal to the process of architecture that is not regarded as design. In school, design is a personal process whereas in practice it is viewed as a co-operative, even as a corporate, experience. Referring to Simon (1966) it could be argued that design is simple, only its environment is complex.

Design is often seen as the cognitive process by which a three dimensional form is generated. This process embodies so many intangible elements such as creativity, intuition and imagination which are essential to research as well. (Zeisel 1981) According to this author the nature of designing involves three activities: imaging, presenting and testing. A more abstract definition of design came from Papanek (1971) who remarked that design 'is the conscious effort to impose meaningful order'.

According to Archer (1965) design involves a prescriptive model, intention of embodiment as hardware, and some sense of originality/creativity. In some definitions of design, logical process and scientific principles have also been incorporated within from the beginning. Fielden et al. (1963) defined design as: 'The use of scientific principles, technical information and imagination in the definition of a structure, machine or system to perform prespecified functions with the maximum economy and efficiency'. Hillier and Leaman (1974) suggest that design is the search for the appropriate transformation or unfolding of prestructures in relation to the constraints imposed by the environment of the problem. 'They conclude that if design method is to be improved then it is more important to study the environment itself than how designers design'.

In defining the act of designing, one often encounters cognitive words such intuition and creativity which are difficult to apprehend. Regarding the question of creativity, it is still clearly a mysterious and largely unknown process. It has been defined as the ability to bring something new into existence, (Barron 1965) a definition which Storr (1972) accepts as a reasonable one for 'the manner in which this process of creation comes about has been found so enthralling that millions of words have been written about it'.

Puzzling and mysterious it might be, one could claim that creative thinking is a product of past experience and knowledge as well as presumably an inherent talent. In his speech to the Academie Francaise in 1753, Buffon purported that '*the human mind can create nothing, and only produces after having been fertilised by experience and meditation, in that its perceptions are the germs of its products*'. (Collins 1965)

Therefore, if one is not dealing with mediocrity, it is reasonable to conclude that the greater the knowledge and experience, the greater will be the possibility of a creative leap. (Newman 1990)

Developments in design methodology and process have attracted a great deal of research and attention from various workers, resulting in a number of design models. Despite the wide disagreement between researchers in terms of terminology in their models of the design process, the following model seems to have some common grounds:

Analytical Phase: [Programming]+[Data Collection]-(observation, inductive reasoning)

Creative Phase:[Analysis]+[Synthesis]+[Development]-(evaluation, deductive reasoning)

Executive Phase: [Communication]-(description, translation, transmission)

In conclusion, it could be argued that the design process can be regarded as both 'rational' and 'intuitive'; the first being the norm in Science whereas the second is relied upon in Art. This implies that scientific rationality and creative artistry can be employed together, by the designers, for the service of design in architecture.

Science serving Design

Science as a system of thought can aid design, and design research in many direct and indirect ways. First, science offers a systematic and rigorous research approach, based on proper *methodologies*, upon which architectural research can be modelled. Second, through its laws and theories, science provides the designer with means like *technical rationality* and *rules of thumb*, that enable him to evaluate design decisions. This is the essence of subjects like *Architectural Science*, taught in the architectural curriculum of schools. Third, CAD tools particularly quick modelling ones can immensely aid design cognition and facilitate the formulation of design hypothesis, i.e a 3D form.

i) Architectural Research and Architectural Science

Research is a systematic inquiry geared toward the creation of knowledge. It is also a methodologically self-conscious activity. Architectural research, on the other hand, has been defined as the 'systematic and rigorous study of the built environment at the level of individual buildings and clusters of buildings' (Joroff and Morse 1984), and, its nature 'is the speculative architectural exploration of alternative forms of urban development'. (Van Schaik 1991).

The curious omission of design from architectural research definitions is surprising since design is so central to both architectural practice and architectural education. To some, design does not constitute research for it cannot produce consistent results. To others, design is a research tool which is as 'foreign to most architects as other research tools'. (Joroff and Morse 1984)

The conflict between science and design has been reported in the literature. For example Lawson (1980) perceives the gulf between science and design as an inevitable conflict that cannot be resolved since science is 'descriptive' while design is 'prescriptive'. He remarked that while science is mainly concerned with understanding the present and predicting the future, design is about prescribing and creating the future.

This is a very narrow view as it doesn't make architecture an obvious candidate for research. It is not difficult to conceive ways in which science might help designers. Looking at the history of architecture one can argue that a new technology (applied science) has always created new architecture. New materials, new environmental control systems, industrialisation of the building process, the introduction of IT and Computing, and new sociological and psychological research findings, have always influenced the way we design and build, and the way we perceive 'personal' space.

The greater the distance between science and design the greater will be the possibility of serious technological illiteracy in the design profession. Such illiteracy, it has been argued (Hanna 1994), will yield a situation where architects will relinquish their traditional role as a design project leader to other built environment professionals. The quick pace of technological and scientific development of new materials, i.e. Aerogels (Hanna 1996) and phase changing elements, and environmental control systems is not matched by sufficient understanding by architects of the scientific concepts behind such development.

A marriage between science and design can be achieved through better integration of architectural science and computer technology (CAD) into design education. This evolutionary step of architectural science to act as a bridge between the 'exact' and the 'inexact' sciences appears to be its natural role. One way to promote the role of architectural science into design teaching is through the introduction of environmental, structural and cost models into the curriculum. Such models are either graphical, mathematical, or computerised. These models, whether descriptive or prescriptive, can be categorised, with an ascending order of complexity into: rules of thumb; design aids; research tools

The idea of using science-based models into design, however, carries with it notions of objectivity and strong bias to 'rationalism'. It is quite acceptable that design remains dominated by an artistic ideology with dominant obsession with creativity. It is unacceptable, however, that architecture should nurture a growing technological illiteracy in the profession that is often revealed by problems of buildability. (Miller 1990)

ii) *Computer Aided Design (CAD)*

The origins of the theory behind CAD can be traced back to Aristotle's concept of a generative system that can provide a variety of potential solutions to a problem. (Mitchell 1977) Generative systems have been utilised in philosophy (the Lullian wheel), literary composition, musical composition, engineering design, and architectural design. Generative systems were systematically used by Leonardo da Vinci for the generation of central plan churches, and by Durand for the creation of plans, elevation and urban forms from different combination of building elements (columns, walls, etc.). Classical architecture was also based on having a fixed vocabulary of architectural elements that can be assembled in different combinations to generate architectural forms. (Summerston 1963) A modern application of this principle can be found in Stiny's (1980) work on 'shape grammar' [generation of shapes and subshapes according to relational rules]. After defining the grammar, a computer can then be used to generate forms and objects in the corresponding language.

Recent work on the role of drawing in architecture (Lawson 1994; Fraser and Henmi 1994; Robbins 1994) claims that despite the use of CAD for the manipulating and editing drawing and for creating photorealistic images, animation and walkthrough, *conventional drawing methods* are still preferred for creative design and design development. It is worth emphasising, however, that despite the importance of sketching in the act of designing, the quality of buildings depends on the designer and the constraints outside the design environment. Also the idea that sketching is designing is flawed as there much more to designing than just sketching.

The uniqueness of sketching as a design tool, as purported by many authors, is an outdated and inaccurate concept. Recent work on the Electronic Cocktail Napkin, 'an experimental computer-based environment for sketching and diagramming in conceptual design' (Gross 1996), is an evidence that CAD can be used for sketching and creative design. The 'Drawing Analogies' CAD system (Yi-Luen Do and Gross 1995) is another example on how computers are currently invading the privacy of conventional sketching at the early design stage. This software is a shape based reminding programme that employs hand drawn sketches or keywords (i.e. 'architect= Scarpa AND place= Venice') to index and query visual databases.

CAD is not a tool; CAD is a medium. It provides an environment to explore and test design ideas by means of interactive three dimensional solid modelling and visualisation. The addition of lighting, colour and texture maps enables the creation of photorealistic images more easily and more frequently during the design process than by hand. (Greenberg 1991) The visual modelling of acoustic behaviour of sound waves within enclosures, and the visual simulation of air movement using CFD (Computational Fluid Dynamics) programmes, are fascinating areas whose impact on design quality requires further investigation. The ability to revisit cities and buildings lost to fire and/or destruction using visualisation techniques and virtual reality technologies, is an area which could revolutionise the way architectural history is taught and researched.

LeCuyer (1996) compared two different approaches to the creative use of computers in design by two world class architects. She remarked that 'while Gehry employs computers in design development, Eisenman uses computer-generated forms as his starting point'. Also recent books on computers in architecture (McCulloch et al 1991; Penz 1992) have shown that computers have changed the way design is being taught in schools and practised in offices.

Computers are currently having a new role in exploring design and teaching of design. Working with traditional methods of paper and pencil, limits architecture students' investigation of design mainly to 2D (plan, section, elevation), while employing CAD enables them to work mainly, in an interactive way, with 3D (axonometric and perspective) images as they can be generated more quickly and more frequently.

Conclusions: Conceptual Framework

Science and the scientific method could be very useful to design and architectural research. Basic theory in the physics and mathematics of heat, light and sound, coupled with knowledge of the crystalline structure of materials, new materials, and new mechanical and electrical services, can inform design. Also the scientific method of research which is based on the 'hypothesis formulation-hypothesis testing' model provides a much needed framework for architectural research. Designers, on the other hand, can play an extremely important role in identifying problems for scientists to solve.

Some remarked that to base design on inappropriate paradigms of logic and science is to make a bad mistake, and that a scientific hypothesis is not the same thing as a design hypothesis. It is extremely difficult to reconcile this view with Einstein's: 'When I examine my self and my methods of thought, I come to the conclusion that the gift of fantasy has meant more to me than my talent for absorbing positive knowledge'. (Bender and Parman 1984)

According to Schon (1987), 'applied science and research based techniques, bounded on several sides by artistry, occupy an extremely important but limited territory in the realm of professional knowledge, i.e. design'. The 'inexact' science of design deals with cases which are not 'in the book' where the designer has to invent and test strategies of her own formulation. Technical rationality should not be the basis of architectural design which deals with 'uncertainty', 'uniqueness' and 'value conflict', nor should it be the yardstick to assess the 'reflective' practitioner unless there is a problem of buildability in the solution. This uncertainty has been the focus of Dewey in viewing the designer 'as a reflective practitioner who transforms indeterminate situations to a determinate ones by imposing a self-constructed coherence on complex, ill defined, uncertain, and incoherent design problems'. (Schon 1987, p. 43)

One could argue, however, a proper relationship between design schools and science schools can be built within a framework of better integration: the former identify unsolved problems to scientists, whereas the latter provide useful knowledge to designers.

Another way of bringing science and design together is through architectural science where certain design propositions can be tested and refuted. This can be done very frequently and very quickly through the use of performance oriented models of CAD.

It is appropriate to reiterate Heath's view of the inseparability of science and design as he remarked, 'the "art" of architecture and the "science" of engineering are not really separate even today as the works of the artist engineers, Millart, Nervi and Arup makes clear'. (1984, p.6)

Finally, the author has developed a conceptual framework that can be used as a basis for programming a future CAD system, that incorporates four neural subsystems: Design, Science, Architectural Research, and Architectural Science (Fig. 1).

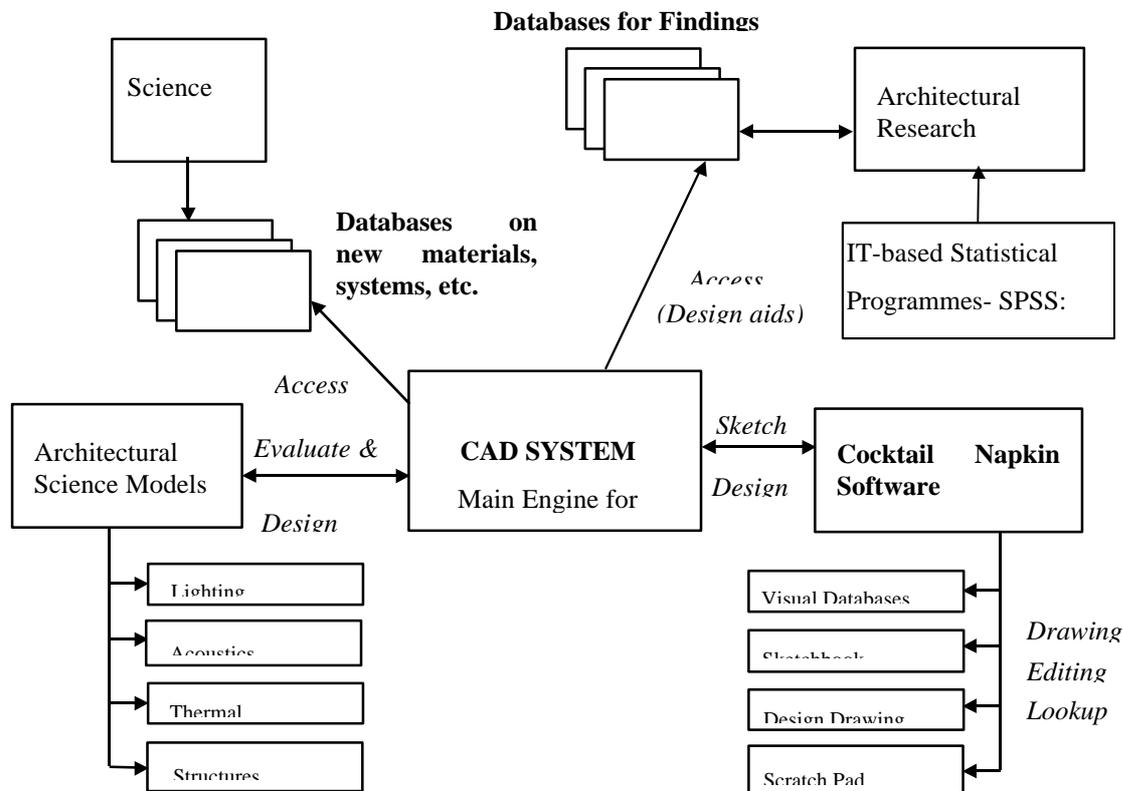


Fig. 1 A Multi-disciplinary CAD System with Neural Sub-system (Hanna, R.)

The paper closes by quoting Aalto: 'The methods of architecture are sometimes reminiscent of those of science, the kind of research that natural sciences uses can also be applied to architecture. Architectural research may well be more methodical than before, but its essence can never be purely analytical. Architectural research must always be more of an art and an instinct'. (Ruusu vuori 1978)

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