

Architectural design – the art and science of designing space, building and the built environment – is a creative and complex task. It involves considerations of form (shapes, structure and configurations) and function (purposes and utilities). Whether form precedes function or vice versa (Janson, 1982; Anderson, 1987), the training and education of architects posits that successful design should combine form and function. Tasks include spatial arrangement (massing, volume, space) for programmatic requirement (capacity, cost, lighting, acoustic) and tectonics (details, material, construction and technology) at various scales from urban design to details.

In architecture, drawings are the primary form of representation, carrying a design from conception to construction. The drawings the architect makes to explore and evaluate alternatives are more abstract and less precise than the working drawing handed to the builder specifying what to make. The earliest representations in this process are diagrams.

The use of drawings to design buildings is a fairly recent phenomenon in the history of architecture. Although full-scale templates of columns are carved in stone at the Temple of Apollo (Haselberger, 1985), it appears that drawing (and hence diagrams) as a vehicle for making decisions about what to build emerged during the Renaissance. See Herbert (1993) for a general discussion; Ackermann (1997) and Branner (1960) for medieval design methods and the development of drawing-based design.

Designers think with diagrams. All design is done with drawings and drawings are done in every design. There are many forms of design drawing. We distinguish between diagrams and other forms of drawing – the sketch, the more formal schematic drawing – and study the relations between drawing forms and various design activities.

Designers start by making diagrams and sketches to explore ideas and solutions. Trained to use paper and pencil to develop conceptual designs, they draw to develop ideas and communicate their thinking. Design drawing is an iterative and interactive act involving recording ideas, recognising functions and meaning in the drawings, and finding new forms and adapting them into the design. Drawing educator Betty

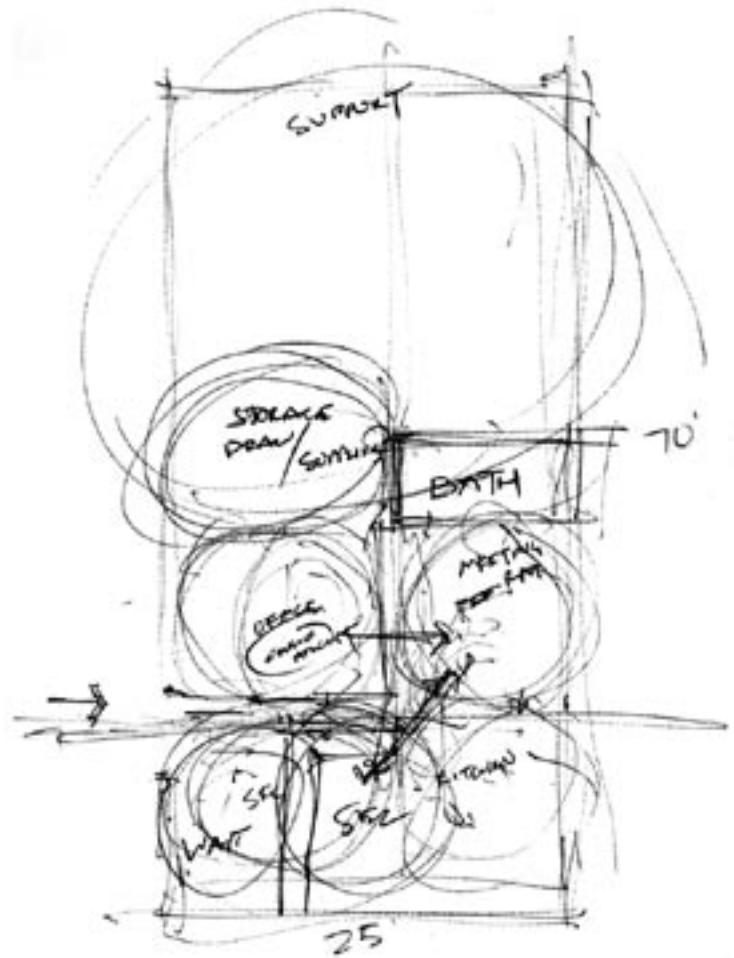


Figure 1 - diagrams showing spatial layout bubbles with labels and annotations.

# THINKING WITH DIAGRAMS IN ARCHITECTURAL DESIGN

Edwards argues that drawing is important not only for communication; drawing actually helps designers see and understand the forms they work with (Edwards, 1979). This theme – that drawing is intimately bound with thinking – echoes throughout the studies we review here.

Architectural design ultimately decides configurations, connections, shape and orientations of physical forms. Even the most abstract diagrams are early efforts to explore and resolve spatial layout concerns. Architectural design diagrams represent not only physical elements, but also forces and flows (eg, forces of sun, wind, and flows of people and materials) using arrows, lines, and other symbols. These symbols convey spatial characteristics such as magnitude and direction.

Following a brief discussion of the types of drawings in design, we focus on freehand design diagrams. We examine the roles of diagrams in design as discussed in several different sources. First, we look at books that teach architectural design skills through drawing. Second, we review recent studies on drawing in design, which employ interviews and surveys of architects' drawings. Third, we look at several designers' introspective accounts of diagrams and design. Finally, we look at empirical studies of the use of drawing and design.

### What's a diagram?

We distinguish diagrams from two other forms of drawing commonly used in design: sketches and schematic drawings. By an architectural 'diagram' we mean drawing that uses geometric elements to abstractly represent natural and artificial phenomena such as sound, light, wind and rain; building components such as walls, windows, doors and furniture; and human behaviour such as sight lines, perception of privacy and circulation, as well as territorial boundaries of space or rooms. A diagram may indicate visual phenomena such as wind, rain and sunshine, sight views and lighting, non-visual aspects such as noise and heat, and functional aspects of the environment.

A diagram is made of symbols and is about concepts. Abstract and propositional, its elements and spatial relations can be expressed as a set of statements. It explores, explains, demonstrates or clarifies relationships among parts of a whole or it illustrates how something

works: a sequence of events, movement or a process. Its symbols may represent objects (eg, a space or a piece of furniture) or concepts (eg, service area, a buffer zone, accessibility or noise). A diagram represents abstractly without detailed descriptions of scale or realistic pictorial representations; it indicates spatial relationships only approximately, using indefinite shapes. For example, a bubble diagram (Figure 1) roughly represents sizes, adjacencies, containment and connections of functional spaces in a floor plan. A design diagram can be spatial, showing relative positions and approximate sizes of rooms, or it can be non-spatial, eg, showing a sequence of building construction.

A sketch, in contrast, is mainly about spatial form. A perspective sketch provides three-dimensional information about a scene, specifying the shape of physical elements and their spatial relationships. Figure 2 'right' shows a birds-eye view of the design for the Carpenter Center for the Visual Arts at Harvard University by Le Corbusier with annotations indicating the layout for different studios (painting, sculpture, exhibition) and the ramp. A plan or elevation sketch may concern the proportions of a building or its components. Figure 2 'left' is a drawing by Leonardo showing detailed layout of the bricks for a buttress construction with interlocking notches. Although a sketch falls short of precisely specifying dimensions and shapes, it provides more shape and dimension information than a diagram. A schematic drawing also differs from a diagram, having features of both a diagram and a sketch. It uses conventional symbols to represent building components and, typically drawn freehand (that is, not drafted with parallel rule and triangle), the schematic drawing retains the spatial feel of a sketch. Drawn to scale, it is more complex and precise than a diagram, yet it does not attempt the accuracy and precision of a working drawing.

### Drawing in architectural design education

Diagrams play an important role in the education of architects. Books aimed at educating architects focus on specific drawing methods and techniques. Lockard proposes that the ability to 'diagram' a context depends on designers' knowledge of related issues in a setting, such

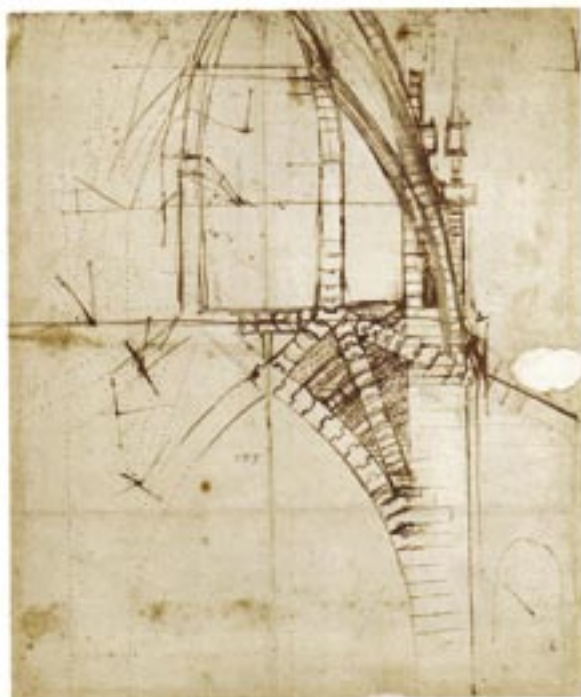


Figure 2 - examples of architectural sketches. Left: Milan Cathedral study, Leonardo Da Vinci. Right: Carpenter Center for the Visual Art, by Le Corbusier.

as sun, wind, vegetation, traffic and surroundings. He argues that diagramming can be used to explore variations of design problems and that it allows our mind to 'see, comprehend and respond' to more visual information than we can remember from verbal notes (Lockard, 1973). Diagrams transform verbal notation to an abstract graphic representation. *Graphic Thinking* (Laseau, 1980) is a guide to making drawings for working out problems, and communicating with others. Laseau describes drawing as a means for design development, a 'diagram' as an abstract graphic language, like verbal language, consisting of grammatical rules and vocabulary. He argues that a verbal language is sequential while a graphic language is simultaneous: 'all symbols and their relationships are considered at the same time'. Laseau calls a 'diagram' an abstraction of architectural programme. Diagrams are a means to express functions, the relationships between functions, and the hierarchy of those functions. They are drawn to present points of concern where shapes have no specific position implications.

Likewise, in *Art and Visual Perception*, psychologist Rudolf Arnheim proposes that to diagram is to represent an object with its properties by 'greatly deviating from its photographic appearance' (Arnheim, 1974). A subway map shows how a diagram uses simple elements to give needed information with clarity. The map displays only topological properties accurately; it reduces and distorts geography by representing roads with straight lines, and it reduces angles to 90 and 45 degrees.

### Diagrams in professional practice

In professional architectural practice designing often begins with a diagrammatic depiction of the architectural programme. Gradually, diagrams are transformed to more complex graphic representations by adding detail. One architect explained designing as 'trying to take a structural diagram, a functional diagram, and a circulation diagram' and 'combine[ing] them' (Rowe, 1987). Architects often make or transcribe diagrams from their design team colleagues for further development (Graves, 1977; Lockard, 1977). An early diagram by I. M. Pei for the National Gallery of Art (Figure 3) extends the axis of the West Building to divide a trapezoidal lot into two isosceles triangles, which became exhibition towers and a right-angled triangle, which became the Center for Advanced Study. The arrows indicate circulation access and entrances.

Case studies of well-known architects focus on connections between design practice and drawing through interviews, observations and works from portfolios. Design theorist Bryan Lawson interviewed 10 famous architects, concluding that they 'find it hard to think without a pencil in their hand' (p141 Lawson, 1994). Colin Rowe (1987) examines how architects and planners use drawings to explore shapes for buildings and public spaces. Rowe explains that diagrams

establish guidelines or rules that help the designer plan and prepare for subsequent exploration. Fraser and Henmi (1994) look at how different drawing techniques influence the making of architecture. They defined diagrams as drawings that engage in a 'self-conscious reductive process', attempting a specific interpretation by excluding information the authors deem 'irrelevant'. They note that architects 'symbolize ... intangible factors such as movement, access, sound, view, function, and time ...' (p110) in diagrammatic form to represent the abstraction and reduction of information.

Diagrams are also used to explore, analyse and synthesise ideas. Dan Herbert's *Architectural Study Drawings* (Herbert, 1993) examines the graphical media and design processes used by six practising architects. He describes a diagram as an analytic statement that may be a 'composite of graphic marks and written notes'. A diagram thus governs and transforms the meanings of verbal statement into a graphic context to solve design problems. He also argues that drawings are more than just a convenient strategy for solving design problems and that they are 'the designer's principal means of thinking' (p1). He argues that designer 'must interact with the drawing' (p121).

In *The Structure and Function of Diagrams in Environmental Design*, Ervin characterised diagrams not only as 'abstract', 'topological', but also as 'prepositional' with low resolution compared with pictorial maps (Ervin, 1989). A diagram deals with organising principles and relations between physical elements. He argued that the use of diagram in designing is a sequence of refinement. For example, urban design begins with a diagram of elements of urban forms such as piazza, building blocks and streets and with their topological relations, then adds details: such as size, shape and tone and using design 'rules' to develop the design. Finally, symbols are replaced by physical elements. Figure 4 shows the design of an inner-city park in Johannesburg, South Africa with annotations of spatial relationships, shapes and configurations of different landscape components for a skate rink named 'City Bowl'. Note the drawing is composed of sketches of elevations, sections and 3D perspective.

Diagrams played an important role in Christopher Alexander's early descriptions of design process. His *Notes on the Synthesis of Form* described the diagram as the 'starting point of synthesis', the end product as 'a tree of diagrams', and design as matching programme requirements with corresponding diagrams (Alexander, 1966). He says 'any pattern which, by being abstracted from a real situation, conveys the physical influence of certain demands or forces is a diagram ...' (p85).

### What architects say about diagrams

We find diagrams in the sketchbooks of famous designers such as Louis I. Kahn (Brownlee and Long, 1991), Le Corbusier (Guiton, 1987; Sekler and Curtis, 1978), Peter Eisenman (Eisenman, 1987),

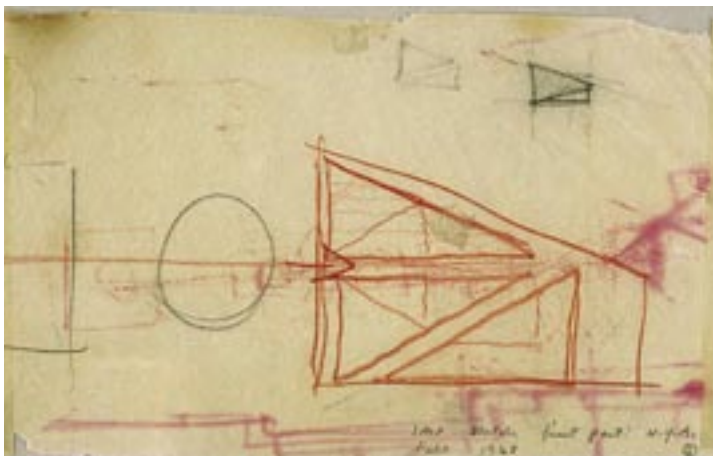


Figure 3, left  
- National  
Gallery of  
Art East  
Building. Early  
conceptual  
sketch for  
building plan,  
autumn 1968,  
by I. M. Pei.  
Crayon and  
graphite on  
tracing paper.  
Figure 4, right  
- Bloemenhof  
Park concept  
design by Fiona  
Garson, Jan  
Hofmeyr and  
Hannah le Roux,  
1998, Troyeville,  
Johannesburg,  
South Africa.

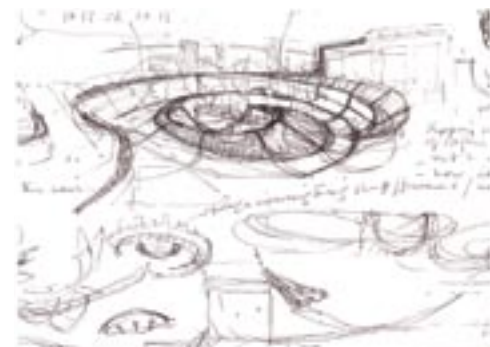
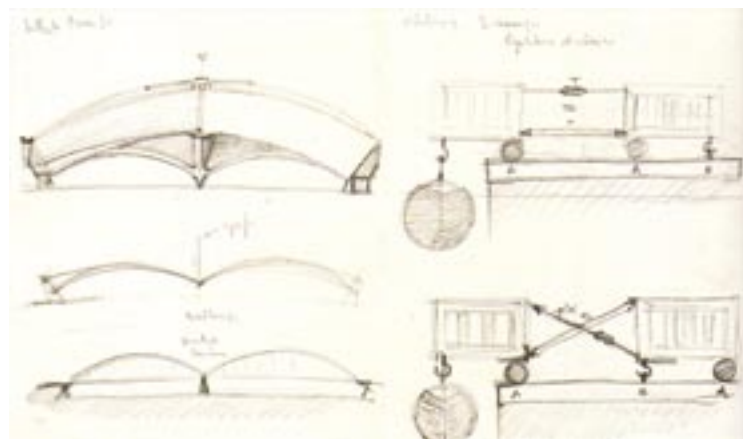
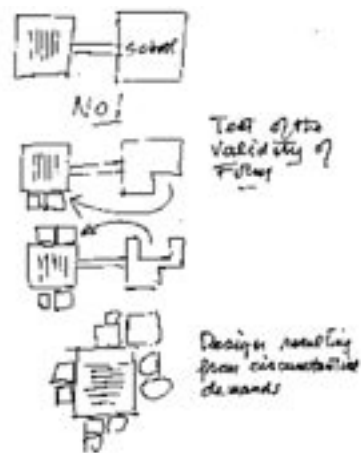


Figure 5, right - diagrams with simple geometric shapes, Unitarian Church in Rochester by Louis I. Kahn (Brownlee and Long 1991). Figure 6, far right - drawing for Gran Via Bridge, Barcelona. The dynamic equilibriums are explored and illustrated in the design of the two arches resting on a single point in the middle of the river.



Renzo Piano (Robbins, 1994) and Santiago Calatrava (Zardini, 1996). For example, Kahn's diagrams of the Unitarian Church in Rochester (Figure 5), use geometric shapes such as circles, squares, arrows and lines with text annotations to explore spatial arrangement of functional spaces.

Pages of Santiago Calatrava's sketchbook (Zardini, 1996) show drawings, diagrams and annotations that record concept ideas, details of mechanisms, joints and connections, and the working of statics and dynamic equilibria (Figure 6).

Many of Calatrava's sketch diagrams show both records of the inner working of the mechanisms as well as the representations of the artifact in different views (plan, elevation and 3D view). For example, Figure 7 (left) shows the intricate design of the roof for the floating pavilion on Lake Lucerne. Independent sheets are moved by its motors, and fixed to supporting pylons. The open and close mechanism resembles a desert flower's transformation during day and night. Figure 7 (right) shows Calatrava's drawings of the foldable doors for the Science Museum, Valencia. The system of triangular doors that rotate around a horizontal axis are represented by connecting lines.

Many architects express the importance of diagrams and drawing in their design process. Graves explains that the 'referential sketch' serves as the architect's 'diary' or record of discovery (1977). It is a 'shorthand' notation, a 'reference' of an architectural theme recorded to be 'used, transformed, ... engaged', elaborated and combined with other sketches in a later composition.

The margins of Kevin Lynch's *Image of the City* (Lynch, 1960) contain a fascinating sequence of tiny diagrams that illustrate symbolically the ideas about the built environment and cognitive maps described in

the test. Each diagram is composed of only a few lines or symbols, yet together the hundred or so demonstrate the diversity of meaning that can be conveyed – or at least illustrated – using a small set of symbols and spatial relations.

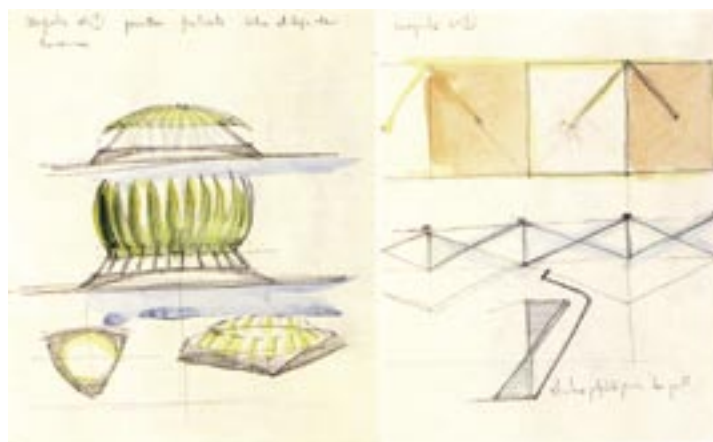
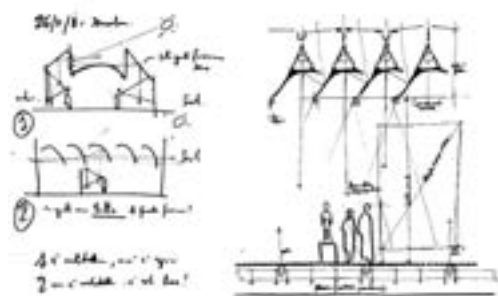
Edward Robbins' interview of Renzo Piano in *Why Architects Draw* (Robbins, 1994) reveals that Piano draws simple diagrams to communicate and explain to clients. Figure 8 shows the sectional views of roof structure for museum lighting and the detailed design of lighting fixture in relation to the viewers and sculpture exhibits.

### Empirical studies

Protocol analysis studies are used to study problem solving in design, collecting both verbal and visual data. In one of the first protocol studies of design, Eastman showed that the representations architects use – words and drawings – correlate with the problems they find and solve (Eastman, 1968). He argues that design is a problem-solving activity performed through sketching. Six architects performed a simple task of improving a bathroom layout through drawing. Eastman documented the design operations they used, the objects they manipulated and the 'control mechanisms' they employed.

A study done by Suwa and Tversky (1996) videotaped architects sketching to design an art museum. While watching the tape, the architects then reported what they had been thinking about. Suwa and Tversky looked at the relation between concepts (as identified by chunks in verbal post-design review protocols) and graphical acts of sketching, arguing that seeing different types of information – spaces, things, shapes, views, lights and circulation – in sketches drives the refinement of design ideas.

Figure 7, right - sketches by Santiago Calatrava. Left: floating pavilion of Lake Lucerne (p33). Right: foldable structure of the doors for Valencia Science Museum (p24, source: Zardini, 1996). Figure 8, below - Renzo Piano's sectional diagram of lighting concerns for De Menil Museum.





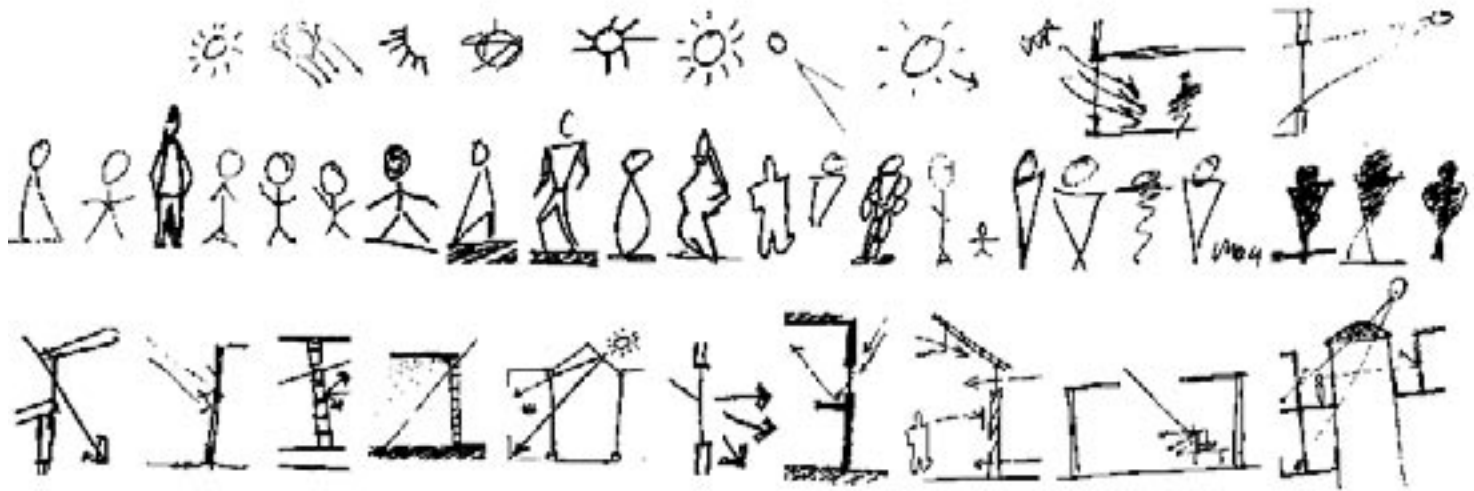


Figure 9 - designers used conventional symbols and configurations for architectural concepts in diagrams.

Donald Schön analysed protocols of architects' sketches in an attempt to infer their design reasoning. Arguing that design reasoning employs design rules (Schön, 1988), he asked architects to make guidelines for entrance locations for a library, given a diagrammatic building 'footprint' (outline). Schön says his protocols show that rules derive from previously known types, and may be 'subjected to test and criticism' by reference to these types. Designers frame a design problem, 'set its boundaries, select particular things and relations for attention, and impose on the situation a coherence that guides subsequent moves'. Schön (1985) uses sketching protocols to illustrate the idea of 'reflection-in-action'. He argues that designers first 'see', then 'move', design objects. He categorises the kinds of seeing and their functions as (1) literal visual apprehension of marks on a page, (2) appreciative judgments of quality, and (3) apprehension of spatial gestalts (Schön and Wiggins, 1992). Schön portrays designing as a 'reflective conversation with materials'.

Gabriela Goldschmidt's design protocol studies examine drawing as well as verbalisation. In 'The Dialectics of Sketching' (1991), Goldschmidt proposes that sketching is a mode of visual thinking and imagery is a conceptual framework for investigation. She views sketching as an operation of design moves and arguments, an 'oscillation of arguments' that results in the gradual transformation of images. Sketching, she argues, is a systematic dialectic between the 'seeing as' and 'seeing that' reasoning modalities. Goldschmidt shows that sketches are not merely representations of images architects already have in mind, but that sketching is a vehicle for design thinking.

All these studies describe the association of thinking and verbal protocols with design drawing. However, none identified the graphic symbols architects use in design. Do's study focuses on associating drawing marks with design thinking. 'What's in a Diagram that a Computer should Understand' (Do, 1995) reports empirical studies on problem description and diagramming to explore the feasibility of diagram based interfaces for design. The experiment used diagrams and stories from a case library of post occupancy evaluations. Sixty-two architecture students were given four tasks: making diagrams from stories, writing stories from given diagrams, pairing diagrams and stories and commenting on existing diagram-story pairs. Do found that 1) designers only use a small set of symbols in their drawings and arrange them in conventional and consistent ways (Figure 9) shows the symbols), 2) designers exhibit different view preference for different concepts (eg, plans or sections) to illustrate

different sorts of problems (eg, spatial arrangement versus getting light into a building), 3) keywords from the stories are often used as labels in diagrams, and vice versa, and 4) designers mostly agree with each others' diagrams.

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