requirements and constraints, and their "good fit" with one another. This is how the potential contribution of alternative courses of action to a possible solution is established. The process of reasoning requires that the ideas in question be represented, so that one can react to them, transform them, refine them, or reject them. Since our cognitive apparatuses are endowed with the capacity for mental imagery, we make extensive use of it in design reasoning: visual imagery is the locus of inner representations in which designers elicit and entertain design configurations. However, despite its powerful affordences imagery is restricted by many factors such as the sharpness of the image, its duration, and our ability to read information off it and manipulate it. External representation is meant to compensate for the limitations of inner representation, and this is why the individual designer resorts to external representation as of a very early phase of the design process. When a designer works with others or reports to them, external representation is mandatory, of course – communication depends on it; but the dialogue the designer conducts with him- or herself, is no less significant.

For the most part, external design representations take the form of drawings, photographs, models, and other artefacts. The drawing is the primary medium of representation, starting with rapid preliminary sketches, advancing to so-called "hard line drawings" and "presentation drawings," and finally technical construction or manufacturing drawings. From the point of view of cognition, rapid freehand sketches are of the greatest interest to us, as they are the closest evidence to the designer's mental processes that we have access to. Fish (chapter 7 of this volume) argues that visual imagery has evolved in humans to assist in hunting, and is geared at fulfilling tasks like pattern recognition and differentiation. Designing complex artefacts or buildings poses very different representational requirements, ones that imagery cannot cope with without external support. Fish stresses that, in terms of evolution, imaging capacities have hardly had the time to adapt to the kinds of requirements that designing imposes. Sketching, in this view, is the easiest and most immediate external device that we can use to amplify mental imagery and to extend it (Fish and Scrivener 1990), and it is well suited to the task of designing new entities. Goldschmidt (e.g., 1991) holds a similar view regarding the relationship between imagery and sketching; she proposed that internal and external representations establish a feedback loop in the course of reasoning about forms and configurations in designing. She has therefore referred to the combined representational activity, in the mind and on paper, as "interactive imagery."

Sketching is, indeed, the most effective, cognitively economical, and rapid means of experimentation at the disposal of the experienced designer (unskilled sketchers benefit much less from the use of sketching in their design search. See, for example, Verstijnen et al. 1998). Sketching is used not just to document what has taken shape in the designer's mind, but also to actually generate form and shape. Shapes on paper can be transformed and retransformed; they can be worked out with more or less detail; they can change size and location within seconds. Moreover, even random marks on paper can be seen as harbouring cues for design ideas and configurations, and sketches are therefore a medium through which discovery and invention are facilitated (Schank-Smith 2000; Suwa et al. 1999). The individual designer who sketches in order to support his or her own thinking may use a personal "shorthand" that permits sketches to remain vague and abstract, which in turn allows him or her to stay non-committal – an advantage in the early phases of the design

process. Sketches can be made in short or long sequences, thus encouraging search for as long as necessary. If need be, sketches can be easily discarded, as the effort involved in their making is modest, thus assisting in the making of a fresh start when one is called for. Sketching is, therefore, most economical in terms of cognitive goal-oriented activity, which explains its wide and universally extensive use in designing (Goldschmidt 2002).

It is therefore not surprising that designers (as well as artists) started making sketches as soon as a suitable medium – paper – had become readily available and affordable, in the last quarter of the 15th century. Figure 9.1 reproduces a sketch by Leonardo da Vinci, describing a design for a movable bridge for military purposes (c. 1480). Leonardo's sketch is explorative and informal; it depicts several ideas and includes notes. It is quite safe to say that we sketch in a similar mode to this very day at the conceptual phase of designing.

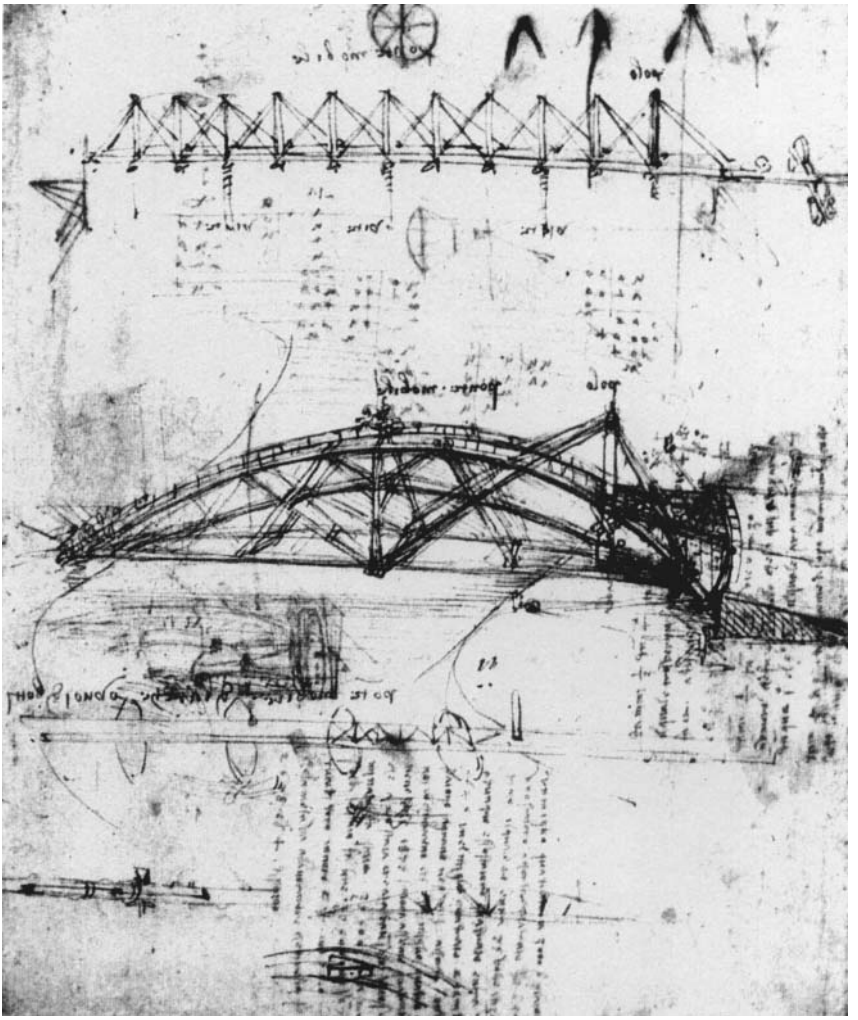

Figure 9.1 Leonardo da Vinci, sketch for a movable bridge, c. 1480. (*Codex Atlanticus*). From *Leonardo da Vinci: Engineer and architect*, edited by P. Galluzi 1987. Reproduced with permission of the Montreal Museum of Fine Arts.