9. Prolegomena to the Recognition of Floor Plan Sketches

A Typology of Architectural and Graphic Primitives in Freehand Representations

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9.1 The architect's papers

Despite being a mixed and transitional case (Goodman 1976), visual architectural representations have been extremely productive and expressive design tools. Drawings have replaced buildings as the primary product of the architect since the Renaissance, in what appears to be an attempt to elevate the status of the master builder to that of a scientific or artistic designer (Evans 1995; Porter 1997). This has resulted into not only many worthwhile buildings but also a huge number of images that document design processes and products from a variety of viewpoints. Our knowledge of world architecture relies more on published images than on personal experience (Evans 1989). In recent years our already highly visual culture has been further enhanced by social and technological developments, including the democratisation of the computer, the proliferation of the Internet and the popularisation related multimedia technologies. These have created an opportune environment for the digital dissemination of visual architectural information, uniquely suited as a repository of architectural imagery.

In most current information systems images are treated as discrete, integral entities. They are indexed through textual annotations and associated with other information items manually. Analysis of images, e.g. in the framework of content-based retrieval, can recover a number of important features, such as the number and shape of spaces or the overall shape of a floor plan. It can also produce the general topological pattern of such features. For practical reasons, however, image analysis is generally restricted to a small number of salient features. These form the basic classification criteria for the image in the framework of specific activities. Therefore, image analysis becomes a deterministic search for the most economical collection of features (Gong 1998). The approach underlying our research is fundamentally opposed to both manual indexing and basic feature extraction, on the grounds that they do not return a formal representation, which could be considered equivalent to the image itself. Drawing from computer vision and image analysis we aim at a comprehensive recovery of primitive parts, identification of relationships between these parts and recognition of emerging structures.

9.2 Floor plan sketching

Drawings of different types are used by architects for a variety of purposes, from freehand recording of visual experiences to design registration and communication. In these types and purposes we distinguish common characteristics, such as an uncertain grounding in geometry, systematic deviations from representational drawing, extensive (and at times redundant) annotating, analytical structure so as to specify form, behaviour and performance in detail.

These common characteristics make architectural drawings compatible to each other, generally flexible but also complex.

One of the most complex types of architectural drawing is the freehand sketch. Sketching combines subjective and objective drawing, in that it is characterized by variable emphasis on the designer's intentions/emotions and information conveyed in the drawing. From a technical viewpoint, sketches are not strictly bound by conventions of architectural drawing, in a way reminiscent of gesture drawing (Betti and Sale 1992). Their flexibility, availability and expressive power means that architectural sketches are applied to a variety of purposes: recording objects and designs (including visual investigations of the built environment), communicating design ideas and concepts, analysing how a design will fit a particular context, and studying building typology (Edwards 1994). Nevertheless, sketches are mostly associated with and venerated for the generation and exploration of central design ideas. This runs contrary to the wide application of sketches in design and analysis, but fits the elevation of the drawing to the level of a primary architectural product.

In our research, we approach sketches as a first step in a long path that leads to a complete design (Betti and Sale 1992), rather than as a self-contained design product. The function of sketching that interests us is the transcription of designs formed as mental images. Such sketches form external representations aimed at unloading/refreshing working memory, thereby also allowing the refinement of image through perception and ultimately communicating ideas to others.

Freehand sketches of floor plans are more schematic (conceptual) than other types of sketches. They follow more closely the architectural conventions of orthographic projection and add elements of diagramming, such as the use of symbols to denote objects, the application of emphasis on critical points and structuring of symbols through their interrelationships. From the viewpoint of recognition, floor plan sketches are arguably more challenging than perspectives, axonometrics or elevations because they are the farthest from pictorial recording. They belong to that intriguing category of representations that may be incomprehensible before one comes to grips with their structure, but become perfectly understandable afterwards (Lopes 1996).

9.3 Architectural primitives in floor plan sketches

9.3.1 Drawing dimensions

A sketch entails several dimensions. These are common to a number of representations, from writing to speech. Each dimension is a self-contained study area, central to one or more sciences or disciplines. The *syntagmatic* dimension concerns the sequential structure of the representation. In a drawing this is the sequence of graphic production, i.e. how the drawing comes into being as one graphic element after the other is added, for example through pencil strokes to a sheet of paper. In comparison to other representations, this dimension is relatively weak in drawings. In written text, for example, the sequence of words in a sentence reflects the syntactic and grammatical constraints of the language. In a drawing, on the other hand, the sequence by which strokes are added is not necessarily related to the two-dimensional structure of the described objects, not to the development of the design in the designer's mind.

The *paradigmatic* dimension is complementary to the syntagmatic one, as it concerns the range of standard primitives used in representation. Drawing primitives are generally graphic objects such as lines, circles and dots. These can be analysed at their own level of implementation mechanisms, as well as at the level of representation symbols (Marr 1982), e.g. closed contours representing discrete architectural objects.

The mechanical dimension relates to the anatomy of the draughtsman in interaction with furniture and materials. Such constraints may seem trivial at first sight, but may determine several representation levels. For example, mechanical displacement of the arm may alter stroke matching. Also changes in starting position may affect direction of rotation around circles (Van Sommers 1984).
The *cognitive* dimension operates on the two interrelated levels of action and perception. Action planning and control constrains syntagmatic and mechanical aspects through e.g. eye movement in response to action, positive feedback, anticipatory pursuit, and eye, head and hand coordination in general (Kowler 1990; Miles and Willman 1993). Also relevant are issues of mental imagery and working memory. These are also involved in the perception and recognition of sketches.
Our research focuses on the paradigmatic dimension, that is, the identification of discrete, meaningful components and their relationships. This is a prerequisite to the analysis of cognitive and computational aspects. For instance, image segmentation into areas tentatively corresponding to known objects presupposes knowledge of the paradigmatic structure of architectural sketches. Other dimensions influence the formation of a sketch out of the basic graphic elements. For example, the sequence of adding graphic elements influences not only the total image but also individual elements.
Figure 9.1 illustrates such influences through three different sequences, A, B and C, for the same sketch. Each sequence consists of three steps, with each step adding one specific piece of information. Despite the near identity of the end products, differences -however subtle- are significant not only for the design approach but also for the drawing itself. In sequence B, step 2 shows the addition of the central circulation axes as a subdivision of the already placed overall form of the building. The same form in the other two sequences is added at the last step, as a way of constraining construction. In sequence C, the axes distort (in step 2) the building form and the relative position of the space bubbles. This happens prior to the introduction of the overall building form in step 3. In sequence C all four spaces are self-contained-bubbles, but in sequences A and B two spaces are partially defined by the external envelope against the backbone of the two circulation axes.

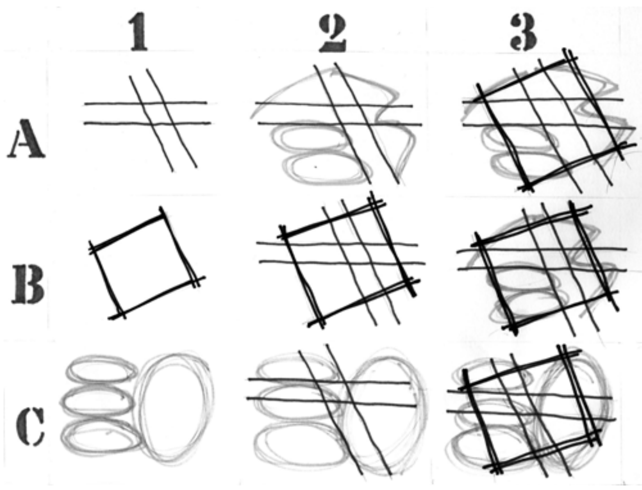

Figure 9.1: Alternative sketching sequences.

Mechanical constrains may also lead to differentiation in the paradigmatic dimension. When drawing simple geometric forms, such as the standard graphic elements of a floor plan sketch, the majority of strokes conform to the preferred stroke directions for the draughtsman's preferred handedness. One important source of exception arises from a tendency to keep contact with the paper as the pencil moves from one linear element to another. The integration of this tendency, as well as the constraints of the drawing media (e.g. ink replenishment), results in a systematic even through variable approach to stroke length, direction and continuity (Van Sommers 1984). Differences and variations due to the syntagmatic and mechanical dimensions are generally impossible to trace in the end product (final sketch). Drawing style varies from person to person, but even the same person may variably use alternative styles with respect to drawing structure and media. Consistency in drawing style and technique is not a priority for floor plan sketching in the early design stages.

9.3.2 Organisational lines

Probably the most frequent type of information one draws in a sketch is organizational lines (Figure 9.2). These are implemented mostly by means of multiple lines as a framework of drawing. They organize composition by extending beyond the outside limits of objects and may cut through objects. Organizational lines are generally transparent -except where they overlap with object contours and relations.

Organizational lines are related to coordinating devices, that is, structures that determine the placement of spatial and building elements (Koutamanis 1996). Coordinating devices are either global (apply to a whole design or a distinct part, such as a wing) or local (refer to a specific component and its spatial relationship to its immediate context). Similarly to coordinating devices, organizational lines are a mixture of abstract spatial relationships, architectural elements and structural associations like grids. A compete sketch cannot consist exclusively of organizational lines. In addition to semantic guidance, organizational lines provide cognitive constraints to mechanical bias towards specific directions due to handedness: they guide strokes that follow a non-preferred direction (Van Sommers 1984). The same applies to relationship lines.

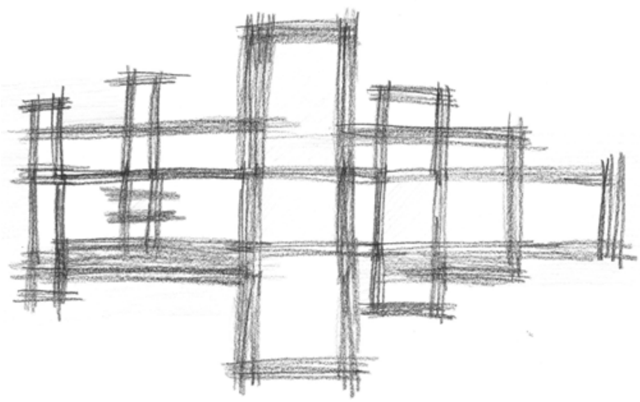

Figure 9.2: Organisational lines.

9.3.3 Spaces

Spaces are generally explicitly represented in floor plan sketches. Sketches consisting almost exclusively of spaces are not uncommon, especially as studies (Figure 9.3). Space contours normally are closed spaces or bubbles, even when the limits of the different spaces is not as sharply demarcated. The perimeter of a space is indicated by single or multiple lines.

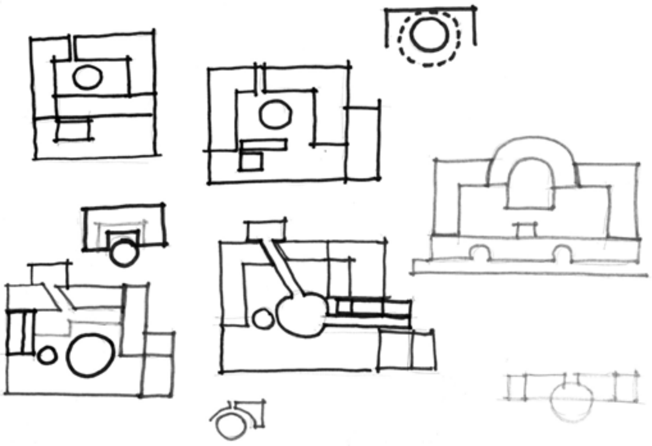

Figure 9.3: Space contours.

9.3.4 Relationship lines and building elements

Given the abstraction of sketches, building elements are seldom depicted as discrete objects. The obvious exceptions are building elements that contribute greatly to the spatial articulation or morphology of the design, such as a dominant wall in a flow space or a portico. More often, building elements are reduced to relationship lines that indicate arrangement (e.g. alignment in a line representing a colonnade: Figure 9.4). The same relation lines may indicate general principles of arrangement such as dominant axes. Relationship lines are related to coordinating devices and organizational lines.

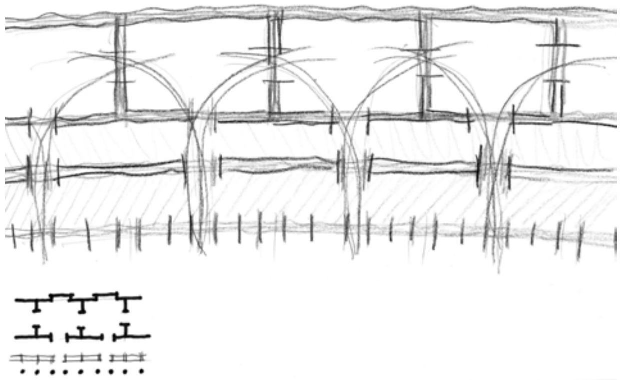

Figure 9.4: Relationship lines.

9.3.5 Positive and negative

Positive and negative, with respect to space and architecture, are charged concepts. In sketches of floor plans we refer to a sketch as being positive when the building elements are drawn (coloured) and spaces are left blank (similarly to conventional architectural drawings). The reverse: coloured spaces that leave building elements blank, is a negative sketch (Figure 9.5). This is frequently applied to so-called figure-ground drawings, which depict e.g. urban structure through the relationship between the solids (buildings) and voids (spaces) of the city (Edwards 1994).

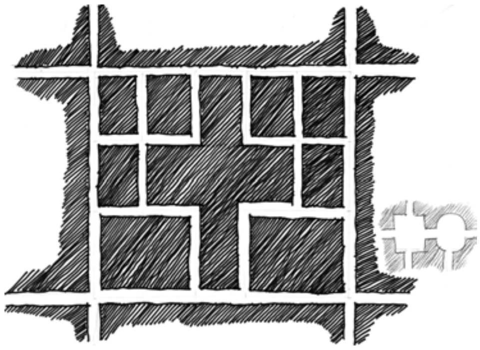

Figure 9.5: Negative sketch.

9.4 Implementation: graphic primitives

A sketch of a floor plan comprises organizational lines, spaces, building elements and relationship lines, usually in a positive manner. These types of information correspond with the level of basic architectural primitives in the representation. One level lower, we encounter the implementation mechanisms, that is, the graphic primitives used to depict the architectural entities. Implementation mechanisms vary with the implementation media and the mechanical constraints each medium affords. The following graphic primitives relate primarily to pen, pencil and paper.

9.4.1 Solid lines

The most general category of graphic implementation primitives is solid, continuous lines. These can be used for practically everything, from relationship and organizational lines to the contours of space or building elements. The arrangement of lines follows a number of general principles, which organize the image into generally discrete even though overlapping parts (Figure 9.6). These principles include:

- Continuation: Formation of closed or, less frequently, open shapes.
- Collinearity: Correlation of structurally similar or connected elements.
- Parallelism: Grouping of two or more lines into e.g. the contour of a path or a grid.
- Simple connection and cotermination: Two variations of the same relationship, which both indicate that the lines belong to the same form. In architectural drawing unrelated lines do not intersect or link, an element that, probably through training, has been carried over to freehand sketching.

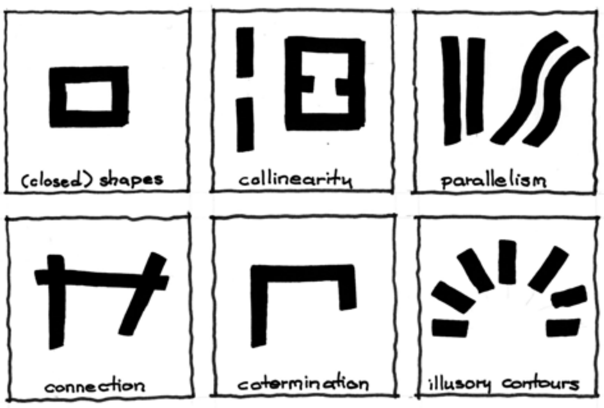

Figure 9.6: Line arrangement.

Under certain conditions unconnected lines combine to form shapes such 'negative' spaces, i.e. illusory contours. An illusory contour is produced by the grouping together of line terminations or by expectations linking together salient features of a nonexistent shape (Kanizsa 1979). Consequently, completion becomes a minor point of attention in recognition, not only for the identification of illusory contours, but also for the removal of local perturbations and other by-products of the mechanical dimension (Figure 9.7).

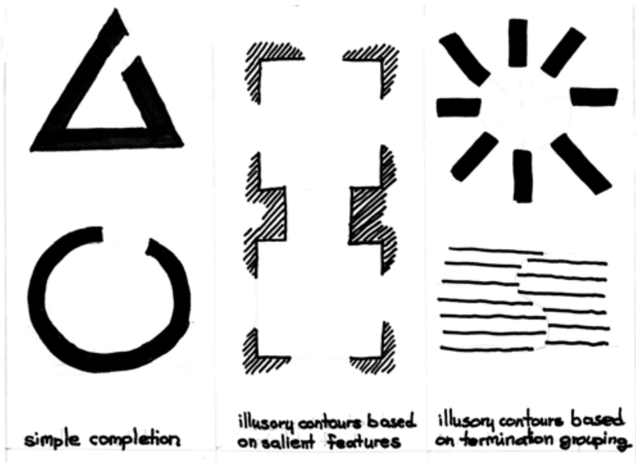

Figure 9.7: Completion

9.4.2 Multiple lines and bubbles

Multiple lines are used to depict organizational lines (Figure 9.2) or limits of spatial elements. Similarly to scribbled-line drawings, multiple lines make the outline of a form fuzzy and indefinitely stated (Betti and Sale 1992). This agrees with the reluctance to make hard commitments in the early design stages, as well as with the informality and metric flexibility of the sketch. Multiple lines may form closed shapes or bubbles, which normally signify spaces (Figure 9.8).

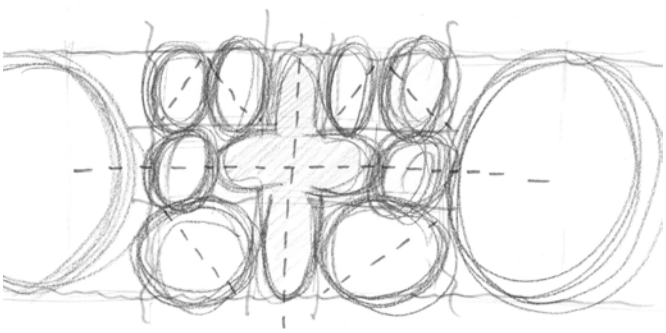

Figure 9.8: Space bubbles.

9.4.3 Broken and dotted lines

Broken and dotted lines represent a diversification of the basic solid line. They normally are used to indicate projecting elements, relationships between building elements (Figure 9.9) or (less frequently) spaces. In addition, they may be used as annotations, e.g. in order to illustrate proportions.

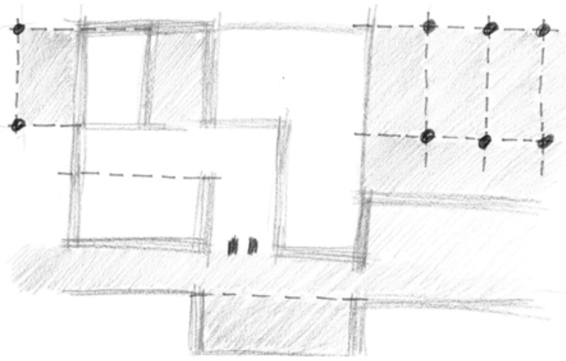

Figure 9.9: Broken lines and blobs.

9.4.4 Blobs

Blobs are small, usually filled surfaces or contours, which generally indicate an isolated building element, such as a column. The same graphic element is used to highlight a focal point of spatial articulation or construction, e.g. an important grid point (Figure 9.10).

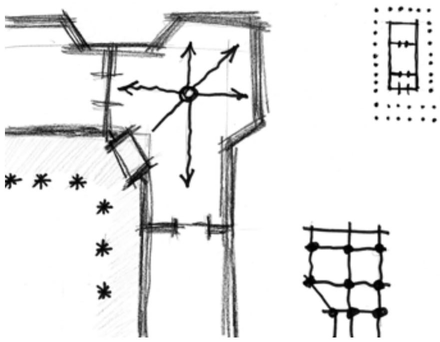

Figure 9.10: Blobs.

9.4.5 Textured and coloured surfaces

Texturing, hatching and colour are applied in order to accentuate spaces or space groups. These are also used to indicate subdivisions of spaces within bubbles or closed shapes, as well as graphic annotations of formal principles and activity patterns (Figure 9.11). Quite often, it is not possible to distinguish between a hatching pattern that indicates a space by filling it and a grid that applies to a yet unfinished area of the sketch (Figure 9.12). In such cases, a grid or web pattern is treated in the same way as a simple texture or hatching pattern. The addition of more information invariably transforms the grid into relationship or organizational lines.

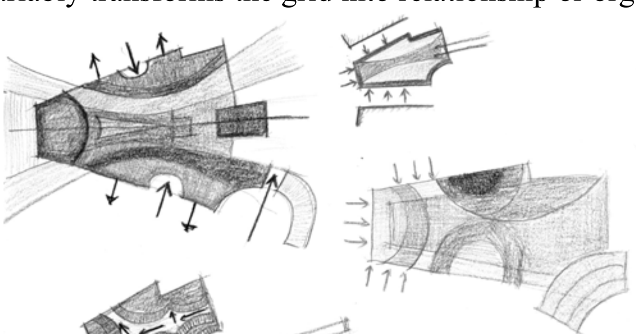

Figure 9.11: Graphic annotations.

9.4.6 Annotations

Annotations are used to indicate properties of relationships, building elements or spaces. They include graphic annotations, such as colour, texture and arrows (Figure 9.11), and alphanumeric annotations, which are placed in the proximity of the annotated elements. Rather than treating annotations as an information category, we have chosen to consider them as a notational shortcoming of the representation (or, at least, a weak aspect in the use of the representation). We consider this a reasonable solution of the pragmatic problems that arise in automated recognition of combined sketch and script, especially given the high redundancy of annotations in architectural drawings. With the exception of graphic annotations that signify a region in the image (i.e. filled spaces) and can be linked directly to an object as properties, our approach initially ignores annotations such as text and arrows. We are considering adding these at a later stage, as comments to either the whole sketch or part of it. In a limited number of cases, alphanumeric annotations could also be attached to objects as properties.

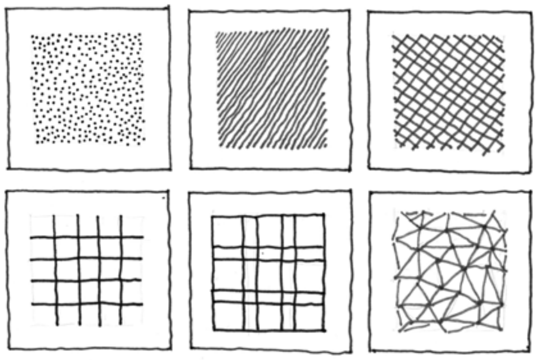

Figure 9.12: Texture, hatch, grid, web.

9.5 Flexibility, layers, and ambiguity

The matrix that emerges from the combination of architectural and graphic primitives reveals that floor plan sketches consist of a very compact set of basic symbols. Even if the set is expanded to allow for different geometries, it still remains manageable and unambiguous. For example, blobs may take a large number of forms, but always remain small, isolated regions that denote discrete building elements or focal points in larger coordinating devices. Architectural primitives are implemented in a small number of related graphic objects. Relationships, for instance, can be solid or broken lines. Multiple lines are used for a relationship if it corresponds fully with a collection of building elements. In such a case, however, it becomes more of an organizational line.

The notational flexibility offered by alternative graphic implementations has a limited scope, but can nevertheless be the cause of ambiguity. In sketching as communication, recognition is aided by the discussion between the designer and the reader of the drawing. Consequently, verbal clarifications frequently guide our perception and understanding of non-standard elements. Another related reason for ambiguity is the transformability of architectural objects in a sketch. What may start as a space contour may become an organizational line and end up as a relationship line. Even worse, designers are frequently uncertain about the type of a particular line and may use sketching to explore their ideas concerning it.

Final sketches are usually less ambiguous and come closer to the conventional floor plan. Most sketches, however, are not as straightforward. In the process of designing and sketching, a drawing may develop a number of superimposed layers, which contain the same information in different variations and implementations. Such a layered structure makes even basic recognition tasks more difficult. For example, segmentation of overlapping organizational and relationship lines is only possible when the two have a difference in intensity or geometry. The use of multiple layers also extends to the carrier of the sketch. A sheet often contains several sketches, which should be read in juxtaposition. These sketches can be variations, alternatives or even complementary: the design is frequently the amalgamation of different parts from several sketches (Figure 9.13).

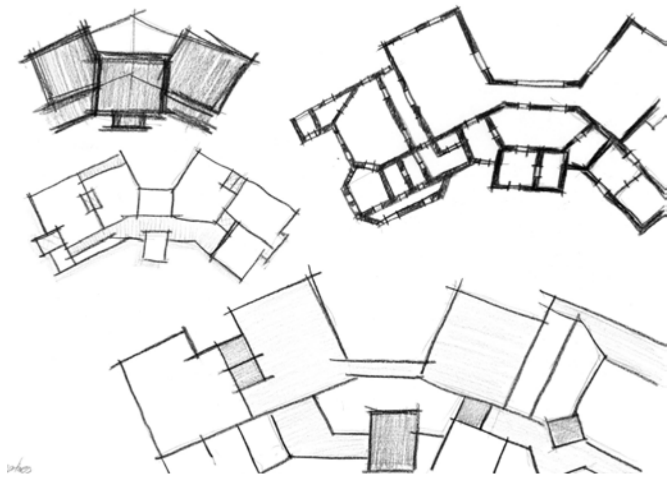

Figure 9.13: Multiple sketches.

The ambiguities and general fuzziness of sketches does not necessarily reduce the reliability and utility of automated recognition. If the recognition aim is to deterministically discover specific features for indexing or provide a single, unambiguous interpretation, as in e.g. conversion to CAD, the flexibility and layered structured of sketches can be prohibitive. If, on the other hand, recognition returns elements of spatial arrangement in terms of a neutral representation, the uncertainties of sketching provide a richer background for the formation and satisfaction of queries and the analysis of formal and functional aspects. A prerequisite to that is the use of multilevel representations, which can accommodate various aspects at different abstraction levels (Koutamanis 1997).

9.6 Discussion

Architectural sketches, especially those of floor plans, are undoubtedly one of the most subjective and mixed visual architectural representations. Yet, sketches have been an efficient medium for communication and design decision registration. This suggests that floor plan sketches contain, possibly with some ambiguity and deviation from the canonical drawing forms, the basic entities and relationships that exist in all structured architectural representations. Recognition of floor plan sketches is facilitated by:

1. The distinction between different types of sketches (floor plans, perspectives, gestural drawings, representational drawings).
2. The analysis of each sketch type, initially at the paradigmatic and semantic level. Other levels also contribute to our understanding of sketches, but only after the essential primitives, relationships and structures of a sketch type have been recovered and organized into a basic representation.

3. The interpretation of the analysis results as a symbolic representation of spaces and building elements, related to each other through overlapping networks of spatial relationships and multiple abstraction levels.

The layered structure of sketches, in combination with abstraction, results into a variable implementation of most entities. For example, relationships between elements may be implicit in the grouping or explicit as one or more relationship lines, as well as textual annotations. If recognition aims at deterministically identifying specific indexing features or at a single interpretation (as in conversion to CAD), the flexibility and transformability of sketch elements pose significant problems. If, on the other hand, recognition returns a neutral, general representation, the uncertainties of architectural sketching can be transformed into a semantically and structurally rich background for relevant queries.

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