Spatial representations as the basis of formal and functional analysis

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ABSTRACT

The proliferation of the computer in the documentation of architectural designs generates a growing number of computerized architectural drawings. As a result, practice is showing an increasing interest in the utility of such drawings. This interest is linked to a fundamental promise of computerization in architecture, the analysis and evaluation of a building’s behaviour and performance during the design process. The main drawback of conventional computerized drawings is that they are restricted to plotting orthographic or, less frequently, perspective projections. This effectively reduces the computer to a mere electronic drafting table and computerized drawings to unstructured, haphazard collections of arbitrarily chosen graphic elements, normally of the lowest possible complexity. The lack of structure and in particular of meaningful, relevant primitives leads to inadequate support even for basic analyses and evaluations. We consider the structure of computerized design representations with respect to the choice of primitives that facilitate automation of analysis and support focused feedback. We argue that current drawing systems are capable of deriving the basic dual network of ‘solid’ building elements and ‘void’ spaces on the basis of user-input descriptions of familiar entities and that this network is sufficient for normative analyses.

1 DRAWING WITH THE COMPUTER

In the last decade CAD systems have emerged as a powerful and popular alternative to drawing directly on paper. The initial investment in infrastructure (hardware and software), re-training of draftspeople and designers, as well as the cognitive and physical inconveniences of relatively small viewing areas, mice and inadequate interfaces appear to be counterbalanced by the flexibility of processing in digital drawing, the compactness and immediate availability of drawing archives and the prestige of new technology. To a minority of users visualization capabilities and connectivity to analyses or communication environments are additional arguments for transferring a large part of designing to the computer. As a result, most design offices have already abandoned the drafting table in favour of CAD systems. Yet, a closer look at the products of digital drawing reveals that little has changed for the majority of drawing practices.
A CAD drawing remains largely a facsimile of its analogue equivalent, bounded by the same motor and perceptual habits. Exactly as on paper, the majority of CAD users draw lines that represent boundaries of objects in an arbitrary, opportunistic manner. The structure of the drawing is of no consequence, as long as its appearance on the screen and when plotted on paper matches the expected image. Attempts to impose modularization of information by means of layer specifications have stumbled on the users' carelessness, the lack of meaningful control and, frequently, the arbitrariness and irrelevance of the specification itself. The projected migration towards object-oriented data structures might present technical advantages and new possibilities for the annotation of graphical entities but can do little to resolve the conceptual problems of adding meaning and structure to a drawing.

Probably the most important reason for the lack of structure in CAD drawings lies in their superficial purpose, to create analogue images of a design's appearance in most cases, prints and plots on paper. Drawing for printing displaces the user's attention from the representation to its implementation. Instead of dealing explicitly with the primitives, relations and abstraction levels that make up the representation of a floor plan, we handle the lines, pixels and ink spots used to implement on screen or paper a description resulting from the application of this representation on specific design entities. The distinction between representation and implementation, between primitives and implementation mechanisms (Marr 1982), has always been a grey area in architectural theory and design, most probably due to the uncertain relationship between architecture and geometry (Evans 1989). In computer-aided architectural design this distinction becomes even more critical, because it (1) largely determines user interaction with the computer, and (2) complicates the current necessary evil of moving between digital and analogue media.

The reason why a CAD drawing should have a formal structure derived from a well-defined representation relates to its utility. We assume that the initial practical goals of computerization in architectural drafting—e.g. flexibility and speed of graphical processing, compactness and wide availability of drawing archives—have been already achieved. In reality practice has still a long way to go but arguably along a clearly defined and rather straightforward path. The area where little is done is the interaction between the designer and the computerized drawing and the prerequisite automated processing of the drawing in order to anticipate user needs. For example, transformation of a two-dimensional drawing into a three-dimensional model still gives trouble to all but the most advanced users. Equally troublesome is the modification of a completed drawing following a change in the design. This frequently amounts to erasing a large part of the drawing prior to starting from scratch with little support from the computer concerning consistency and completeness. Last but not least, even basic analyses, such as floor are measurements, are usually not possible to automate in the average CAD drawing. The lack of structure and of relevant primitives means that such analyses must be performed interactively and added to the drawing declaratively as textual or other annotations, structurally unrelated to the graphic elements they refer to. The resulting redundancy and lack of coherence pose serious limitations to the reliability and efficiency of digital drawing, especially with complex designs and long, complicated processes (e.g. those involving multiple feedback loops).
We propose that the solution to such conceptual and practical problems is the application of formal representations to digital drawing. This solution includes a large number of intervention levels, ranging from the choice of primitives and correspondence between representation and described entities to constraint propagation on the basis of abstraction into local and global patterns (Koutamanis 1996). In this paper we concentrate on the basic level of the primitives and their interrelations. The reason for this choice is relevance to practice. A digital drawing comprising useful, meaningful primitives provides the means for linking the designer’s mental images and conceptual models to the structure of the drawing. This allows more efficient and effective interaction between the computer and the user and facilitates comprehension of user requirements concerning the manipulation of a drawing, including analysis and evaluation.

Concentration on the basic level of primitives and attention for the fundamental problems of practice signifies a necessary change in research priorities. Following the democratization of computational technologies we are experiencing naïve, frequently even solipsistic tendencies. These reveal ignorance of prior research in the computerization of architecture. Given the bottom-up character of electronic democratization, we believe that the transfer of research results to practice should commence at the basic levels CAD and visualization systems address. The first step is to justify the investment in a well-defined representation by automating analyses and providing feedback to design. Subsequently to that we can proceed to more advanced applications of research products, which could further reform and redefine practice.
It should be noted that the lack of structure in architectural CAD drawings is not unique to architecture or drawing. Even in applications such as text processing, whose primitives (words and characters) are closely linked to the structure and development of the digital computer, we encounter an inexplicable disregard for structure, layout and economy. In the average text produced by the average user we can expect space strings instead of tabs, opportunistically inserted tabs instead of margin adjustments, and a cavalier treatment of text styles. As a result, alterations to the layout of a text frequently become too time-consuming and cumbersome. Also slight changes in the content of the text may require adaptation of an inadequately flexible layout that uses the wrong means for achieving a particular effect. Similar shortcomings also characterize the use of spreadsheets, database management systems and multimedia. All these are arguably part and parcel of the democratization of the computer and signify that computer literacy should go beyond general-purpose facilities and skills. Specialized and theoretical knowledge contributes to the comprehension and systematic use of the computer, from the basic levels of using CAD systems to the design methodology that structures the digital design process (Mitchell and McCullough 1995; Schmitt 1996).
2 DRAWING STRUCTURE

In our analysis of drawing as a representation we assume the structure and capabilities of conventional drafting systems. These include a variety of graphic primitives with different dimensionalities, facilities for annotating these primitives with e.g. colour and text and techniques for defining groups of graphic elements and annotations (modularization of information), notably layers. For the moment we choose to ignore another crucial aspect of CAD systems, standardization of information into re-usable symbols and modules. The reason is that, from our perspective, standardization could be viewed as an elaboration of primitives and grouping. Moreover, it poses questions pertaining to standardization in building and to communication between design and construction computational facilities, which are beyond the scope of this paper.

The foremost component of a representation is the collection of primitives, i.e. the entities described by the representation and the precise properties of these entities that enter the representation. In the computerization of architecture research has traditionally concentrated on the solids’ (building elements and components) and the (Stiny and Mitchell 1978; Steadman 1983; Yessios 1987). Spatial and building elements are normally treated as integral, geometric objects with two or three dimensions, depending on the dimensionality of the representation.
The choice of spaces and building elements as the basic primitives of architectural design agrees with most levels of design thinking, including most normative analyses. For example, a comparison of a design to the floor areas specified in the brief or in regulations normally refers to the projection of such elements in the two dimensions of the floor plan. In several cases the third dimension (height) is also of importance but generally two-dimensional projections are implied in the definitions given in regulations and specifications. Accordingly we represent spaces and building elements with surfaces and/or volumes. The precise implementation mechanisms used for spatial and building elements (polylines, 3D faces, regions, etc.) are a matter of manipulation possibilities and requirements. Each type of geometric elements has advantages over the others, which might make it more appropriate than other alternatives for a particular task. Choice of implementation mechanisms is simplified by the transformability of most geometric primitives (including the ability to generate other types of primitives with the same geometry). In general we have found two-dimensional polylines to be the most amenable geometric primitive. These can be used to represent the perimeter of a surface more consistently than most two-dimensional surfaces and offer a stable basis for the generation of more advanced two-dimensional and three-dimensional geometric primitives. In addition, they are not far removed from the line segments draftspeople routinely use nowadays. Instead of drawing loose line segments, one simply draws the segments of each perimeter consecutively, in an unbroken closed series.
Building codes and regulations also provide guidelines concerning the types of elements that need be represented and distinguished from each other. These are refinements of the generic categories of spaces and building elements. For example, the Dutch norm NEN 2580 defines the areas and volumes that apply to the analysis and measurement of buildings (NNI 1997). The definitions in NEN 2580 follow generally established principles of position and function, such as the distinction between use and circulation spaces and between exterior and interior walls. Further distinctions are made on the basis of local cultural patterns, e.g. the ways usable and rentable areas are calculated, and technologies used for measurement. The norm makes a point of eliminating relatively small perturbations in the form of a space, presumably because it assumes measurement of areas on a drawing on paper rather than in a digital drawing, where complexity of form does not normally make measurement more time-consuming and labour-intensive.

Most categories encountered in codes and regulations imply integral, distinct entities. This means that each category can be implemented as the basic non-geometric property of a space or building element, usually by placing it on the appropriate layer. There are two exceptions to this, both relating to alternative descriptions or definitions of a space. The first derives from abstraction depending on the design stage. For example, in the earliest design stages an architect may ignore the geometric properties of building elements and focus instead on the spaces. The schematic floor plans used for this purpose (Figure 4) are also common in formal analyses, e.g. typological studies. The transition from schematic to full floor plan and vice versa (continuity)
represents one of the conceptual and technical challenges that remain to be resolved satisfactorily in practice.

The second exception relates to the purpose of a measurement and external local constraints. For example, in the Dutch norm NEN 2570 implies a use space can be measured in two different ways. Generally the perimeter of the space lies on the interior face of bounding building elements. However, with respect to the measurement of rentable area, the space extends to the interior face of the glass pane of bounding windows. Variability in measurement suggests also variability in the definition of relevant entities. In most cases variability is achieved in an additive fashion, whereby the basic definition of e.g. a space remains unchanged under all circumstances. Extensions are represented by supplementary spatial elements, which are added to the space when and if needed.

Most types of analysis and evaluation refer to solids’ and voids’ in a building as two complementary networks of elements which fully describe the spatial arrangement of the building. Relations between the spatial and building elements can be critical for the categorization of the elements themselves, as well as for dynamic design aspects, which investigate transition from one element to another (Koutamanis and Mitossi 1993). These relations are implicit in the relative position of the spaces and building elements and constrained by their layers they belong to. For example, pedestrian access between two distinct spaces is possible if there is at least one element belonging to the layer (category) of doors that is adjacent to both spaces. Automated recognition of relations between entities generates the dual network of spaces and building elements for the tasks that need explicit relations and to the extent required by the tasks. Under other circumstances relations remain implicit in the drawing. This keeps the drawing relatively compact and neutral. Also modifications to the drawing do not involve verification and adjustment of complex, multiple relations between entities.

3 ANALYSIS TYPES

Most common analyses in architecture, in particular formal ones, are normative in type (Koutamanis 1997). Normative analyses rely primarily on integral, identifiable spatial and building elements subdivision (cf. Van Leusen & Mitossi, elsewhere in the present volume). For example, the floor area analyses prescribed in the Dutch norm NEN 2580 refer to clearly identifiable spaces, volumes and building elements (NNI 1997). The type of each entity in the representation (as denoted by layers or other grouping devices) is generally sufficient for determining its contribution to the different analyses. Occasionally relations between entities and additional properties modify their categorization, especially with respect to refinements of the original, basic categories which correspond to more detailed or focused variants of the analysis, e.g. distinction between different users of communal rentable area.

Functional analyses, i.e. analyses concerning activities in and around buildings, can also be normative in character. These too refer to spatial and building elements, usually with emphasis on the relations between elements. For instance, analyses of pedestrian circulation in buildings are represented by subgraphs of the network of
spaces (Koutamanis and Mitossi 1993; Koutamanis 1995). These provide an abstract representation of dynamic patterns and of human interaction with the built environment. Other types of activities are studied within each space and may lead to decomposition of the integral space primitives, at least conceptually. This can be achieved by treating a space as a container of included spatial primitives that correspond to e.g. the action planes of the analysed activities. Such forms of decomposition could lead to the definition of new spatial primitives, founded not in architecture but in cognitive science and ergonomics.

Normative analyses have severe limitations, especially with respect to precision and design guidance. Dynamic aspects, natural phenomena and human interaction with buildings generally deserve and frequently require more analytical treatment on the basis of advanced models and technologies. In particular simulation and scientific visualization are well suited to the detailed analysis of built form and its performance (Koutamanis 1995; Koutamanis and Mitossi 1996; Mitossi and Koutamanis 1996). Also these analyses rely for input on the primitives of the spatial representation and their relations. Moreover, they use the spatial representation or one derived from it for output. For example, the results of a climatic analysis can be depicted as patterns in a space that take the form of e.g. zoning or similar subdivision (cf. Den Hartog et al. elsewhere in the present volume). Such subdivision also relates to possible new spatial primitives, which analyse a space into a configuration of flexible, partly anthropocentric, partly adaptive geometric planes.

REFERENCES


