Computer-aided Extraction of Morphological Information from Architectural Drawings

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The objective of the research reported in this paper is to design, implement, and test a computer-based system which allows its user to: (1) extract automatically the geometric, topological, and spatial structures of an architectural plan, (2) extract morphological information, such as axes of symmetry, hierarchical structure, proportions, and modularity from architectural plans, and (3) compare morphological information of classes of architectural plans. Computer vision and pattern recognition techniques are used.

Related Research

In certain applications in engineering, the aim is to use mathematical models to create real objects. In reverse engineering, the aim is to use real objects to create mathematical models. The concept of reverse engineering is used extensively in the design and manufacturing of industrial products. Therefore, a designer creates a clay model of the product. The clay model is then scanned using a laser scanner. Such scanners detect the location of discrete points on the surface of the clay model. These points are entered as x, y, and z coordinates into a data file. A computer program reads the file and tries to fit a mathematical model (e.g., superquadric, cylinder, cuboid) to the data. The parameters of the mathematical model are then used to drive machines that shape the molds that will be used to produce the industrial product, the one that was originally made of clay.

The process of reverse engineering can be related to architectural form-making. There, a designer sketches a building plan on a piece of paper. The sketch is then scanned. The scanner detects the brightness of discrete points over the surface of the paper. These points are entered as x and y coordinates into a data file. A computer program reads the file and tries to detect lines, text, symbols, and patterns in order to create a CAD model of the sketch. Further, higher level entities may be created that represent accurately the building. The process of reverse engineering bridges the gap between traditional form-making and CAD modeling.

Along with the popularization of Computer-aided Design (CAD), it has been becoming increasingly necessary and desirable for a computer to recognize drawings and diagrams. The recognition process can be used not only as a means to input information into the computer but also to extract and compare morphological attributes. Methods exist for inputting and recognizing engineering drawings and diagrams. This is primarily because they are drawn to conform to specific standards. In contrast, architectural drawings are not always prepared in accordance with standards. The problem of reading, recognizing, and automatically extracting morphological information from them remains unsolved. It is this problem that this paper focuses on.

Predicated on the assumption that designers derive knowledge from past solutions to form-making problems, this paper focuses on the techniques by which the morphological information which is

structure.7 To match the accelerated pace of concept modeling, designers must accelerate the processes of developing mature powers of perception.

• Visual notation is an important application of traditional freehand representation that could provide a rich means for developing perceptual sophistication.8 Visual notes combine written and graphic notation in the traditions of the
contained in building plans can be extracted automatically and entered in a knowledge base. Conceptually, this is part of a larger project which entails investigating how knowledge can be incorporated in a CAD system in a manner which aids and supports the form-making process. Conceivably, the approach used here is, wholly or partially, applicable to the problem of extracting morphological information from graphic representations used in a variety of disciplines (e.g., art, architecture, engineering).

**Morphology in Architecture**

Although the word “morphology” has been used only after the Renaissance, the systematic study of architectural form is much older. The importance of the attributes of form, such as symmetry and proportion, was emphasized by Vitruvius in the 1st century A.D. For example, he assigned temples to classes based on the spatial disposition of their columns in plan (Figure 2.1).

![Figure 2.1: Classification of Temples According to the Arrangement of Their Columns (from Vitruvius, The Ten Books on Architecture (trans. Morgan, M. H.), New York: Dover Publications, 1960, p. 76)](image)

Da Vinci explored the configurational possibilities of central-plan churches in an attempt to develop a system for the generation of new churches [Da Vinci 1901]. His system focused on two classes of church plans: circular and cross-shaped (Figure 2.2). By specifying a point on a plane he developed rules for generating central-plan buildings. Da Vinci’s system was an attempt to abstract specific plans, formulate rules that describe their morphological behavior, and then use these rules to generate new plans.

![Figure 2.2: Classification of Temples According to Their Symmetry Axes (from Da Vinci, L., Notes et Croquis: Architecture Civile, Militaire et Navale (trans. Simon, E.), Paris: Rouveyre, 1901, p. 76.]

Coordinate and proportional systems were explored by Dürer in his Geometry and in his Treatise on Proportion. In the latter [Dürer 1613], Dürer shows how facial characterizations and expressions can be transformed through coordinate mappings (Figure 2.3).

![Figure 2.3: Some of Dürer’s Physiognomic Studies](image)

He demonstrated that a face can be viewed as a parametric transformation of a standard schema. Later, this method became popular among botanists and biologists. By setting up a coordinate system they could describe variations of the form of plants or animal skeletons and, in some cases, even predict the form of extinct species [Thompson 1961].

Durand was the first theorist to study architectural morphology systematically and to produce a method of approaching architecture as a language with a vocabulary and rules. Durand’s method entailed...
decomposing the plan of a building into two "basic irreducible elements", walls and columns (Figure 2.4). By combining these two types of elements on a rectangular grid he was able to produce a variety of building plans. Conversely, by abstracting building plans into configurations of walls and columns he was able to categorize them according to their shape. Such a classification is based not on functional, historical, or structural criteria but on morphological criteria.

Figure 2.4: Horizontal Combinations (from Durand, J.N.L., Précis des leçons d' Architecture. Paris: Ecole Polytechnique, 1802)

Since the time of Durand, the form of buildings has been analyzed in various ways. Often, to analyze a building morphologically, a diagram or set of diagrams is used. Diagrams are drawings intended to convey essential characteristics and relations. Le Corbusier suggested that "architectural abstraction has this about it which is magnificently peculiar to itself, that while it is rooted in hard fact it spiritualizes it, because the naked fact is nothing more than the materialization of a possible idea" [Le Corbusier 1970]. As such, diagrams can focus on specific physical attributes, thereby facilitating the comparison of the focus of buildings. In other words, by eliminating all but the most important considerations, diagrams make those that remain both dominant and memorable [Clark and Pause 1985].

In a sense, a diagram is an abstraction of a building, in which, for the purposes of morphological analysis, some aspects of its form are extracted and emphasized. According to Liou, studies of architectural form fall under three categories [Liou 1992]. The first may be called the "relational approach," the second the "constructive approach," and the third is a combination of the two. The relational approach places emphasis on the relations between the parts of a building and between its parts and the whole (Figure 2.5). The morphological attributes of a building are explored with reference to its overall configuration. For example, Durand's analysis of buildings into geometric shapes was based on the disposition of walls and columns. There are many researchers and educators who have analyzed the form of buildings using the relational approach. Prominent among them are Baker [1989], Ching [1979], Clark and Pause [1985], Haraguchi [1988], Krier [1988], and Tice [1987]. It should also be noted that, in addition to researchers and educators, many architects including Le Corbusier [1974], Meier [1984], and Holt [1989], employed diagrams to illustrate their form-making ideas.

Figure 2.5: Relational Analysis of Palladio's San Giorgio Maggiore, Italy (from Clark, R. and M. Pause, Precursors in Architecture, New York: Van Nostrand Reinhold, 1985, p. 56)

The constructive approach focuses on the form-making process of a single building or class of buildings and presents morphological information in a stepwise fashion. Each step uses the preceding one as a point of departure. The idea is to show the process of form-making of a building. This process does not necessarily illustrate the process actually used by the architect. The point of such analyses is to explore the "logic" of the building's form. Architects, such as Aida...
[1990], Eisenman [1978], and Meier [1984] often employ this approach to illustrate their form-making ideas (Figure 2.6). Often, theorists and historians such as Frampton [1987], Glass [1975], and Trevisiol [1982] use constructive diagrams to illustrate their conception of the form-making process used to design a building. It should be noted that shape grammars are examples of the constructive approach.

In general, analyses of the morphological structure of buildings can be seen as systematic investigations which aim at discovering the concepts, principles, and rules underlying the derivation of architectural form. Hence, it may be argued that analysis is the main tool used by investigators to explore, discuss, and explain the process and product of form-making. Thus, knowledge concerning the morphological structure of notable buildings and classes of buildings can be acquired.

Computer-aided Extraction of Morphological Information

The work presented in this paper focuses in three directions. The first direction is the design, implementation, and testing of a computer-based system which allows a user to extract automatically the geometric, topological, and spatial information of a plan. The second direction focuses on the extraction of morphological information from plans, such as lines of global and local symmetry, hierarchical structure, proportions, and modularity. The third direction entails implementing a computer-based system which is employed to compare morphological information of classes of plans. Computer vision and pattern recognition techniques are used to investigate, analyze, and compare plans of buildings from a morphological standpoint. Such techniques can contribute to detecting differences or similarities among plans.

Computer-aided extraction techniques belong to a family of techniques referred to as computer vision systems. In general, computer vision systems attempt to recover useful information about the three-dimensional world from image arrays of sensed values. Vision algorithms try to detect relations among image data. These data are numbers representing light intensity or depth range. A typical vision system operates in the following manner:

1. Clears the raw image data from noise and outliers, that is, from extreme or missing information.
2. Detects features such as edges and lines. This is done by observing local changes of the image’s intensity. The detection of the geometric information is similar to that of solving a statistical regression problem.
3. Models the data in parametric form. This is usually referred to as segmentation and reconstruction. Here, the main task is to fit models to the image data. The process may employ regression techniques to fit a model or may deform the model to fit the data.
4. “Recognizes” objects. This task is usually accomplished by comparing the sensed data to a given model. If a match occurs the object is assumed to be “recognized,” otherwise it is labeled “unknown.”

Research in the area of architectural document analysis is recent. Therefore, the pertinent literature is quite limited. One of the purposes of this paper is to bridge the gap between computer vision and architectural analysis by addressing theoretical issues of morphological analysis through advanced computer vision techniques. Only a few systems for the recognition and interpretation of mechanical and electrical engineering drawings have been developed [Fiiji et al. 1990]. These systems incorporate knowledge about the type of drawing to be processed.

Howard’s End

MACHINE - SPACE - AGENT - ???

ACADIA 1994
In architecture, most computer systems are oriented mainly toward form-making. One attempt to extract information from architectural plans that goes beyond simple line and text identification has been reported by Koumanakis and Mitoro [1992]. They described a technique for extracting architectural elements. The system extracts skeleton lines from architectural drawings and produces a primitive model of a “bubble diagram.” Another system for extracting architectural elements has been proposed by Yessios and his collaborators [1989]. Although intended to work as an expert system for library design, it addresses issues of form-extraction. The form-extraction part of the system was never implemented on the computer, but there are descriptions of techniques for extracting an architectural CAD model.

Implementation and Results

AELI (Automated Extraction of Line-based Images) is a computer system for processing, editing, and managing two-dimensional line-based images. AELI is implemented on a Unix environment. The AELI software is written in the C programming language using the Motif® graphics commands. The Motif® routines perform all of the graphic interfaces which have been developed to take advantage of the capabilities of the RISC workstation, primarily speed and color. The C programming language has been used to implement all the algorithms related to image processing.

In the following paragraphs three plans are used to illustrate the process of extraction. The one on the left is Villa Malcontenta by Palladio, the one in the middle is the Ueda residence by Tadao Ando, and the one on the right is a Greek vernacular building. Figure 4.1 shows the scanned gray scale image of the plans.

The extraction process consists of the following steps:

1. Each image is transformed into a black-and-white binary image. Each gray value of the image ranging from 0 to 255 is changed to 0 or 1 depending on an intermediate number, called “threshold.” In this case, the threshold was set at 128. If the gray value is greater than the threshold, its value is changed to 1 (black), otherwise it is changed to 0 (white). The threshold value is selected by creating a histogram of gray values. A histogram is a graph which maps all the gray values of the image on the x-axis and the number of points found to have that value on the y-axis. Usually, a histogram has a peak-valley structure. The threshold is established by finding the shallowest valley closest to the highest peak and selecting the lowest value exhibited in that valley.

2. The image is cleaned from outliers, that is, salt and pepper noise. This is done by applying a median filter. The median filter checks the neighborhood of each pixel and assigns the average value of all neighbors to that pixel (Figure 4.2).

![Figure 4.1: Gray-scaled Images of the Three Plans](image1)

![Figure 4.2: Filtered Images](image2)

Choosing Your Metaphor

The development of computer applications can be viewed as shifts among operating metaphors. Initially computers and their operating software were seen as machines or tools designed to help us perform specific tasks such as calculation and writing. They were then seen as environments, electronic “spaces” in which to arrange information, graphics and finally three dimensional objects.
3. Now the image contains only black lines and/or dots that correspond to walls and columns. Each line in the image is thickened to "clog" the openings and to reveal the "outline" of each "room." Pixel growing is used to extract the pixels that are inside the thick lines. Pixel growing entails a recursive algorithm which starts with an initial pixel value and searches all neighboring pixels successively to find a pixel whose value is below a certain threshold. If the neighboring pixel's value is above the threshold, the algorithm checks the value of the next neighbor. This is repeated until a pixel value is found which is below the selected threshold. Then, the shrunk rooms are expanded to their original size. Each set of pixels is examined to extract the boundary points, create a chain-code, and extract the highest inflection points to create a polygon. This process is reversed to extract the exterior curve (Figure 4.3). Now the interior is white and the exterior is black. Each polygon represents a room, that is, a void (Figure 4.4).

4. At this stage, openings are detected and a graph representation is constructed. To do this, each room's boundary is traced. If a white pixel is detected it is "grown." The set of grown pixels is traced again. If any of the pixels in the set is adjacent to another room or the exterior, the set is marked as an opening and the rooms adjacent to it are connected. After all the openings have been detected the graph representation is constructed by creating a circle whose area is half the room's area and is connected with a line to other circles representing rooms that are physically connected to it. Rooms connected to the outside are drawn as circles of double thickness (Figure 4.5).

Figure 4.3: Steps in the Process of Extraction of the Geometric Structures.

Figure 4.4: The Geometric Structures of the Plans.

Figure 4.5: The Graph Representations of the Plans.
5. The spatial structure of the plan is extracted by looking in the neighborhood of each corner and each edge of each cell. None, one, or two or more corners are an indication of an L, T, or X type joint or an L type edge. The exact type of each joint and each edge is found by checking the skeleton line and the type of wall and then identifying the specific joint or edge in a table of all possible joints (Figure 4.6).

![Figure 4.6: Wall-joints.](image)

6. Axes of symmetry are found by first extracting the orientation line for each room and then checking if the line is also a symmetry axis. The orientation of each shape is found in two steps: first the center of mass for the shape is detected, that is, the average of all points contained in the shape. Second, the angle $\theta$ of the axis of the least moment of inertia is obtained. Now, the first point that defines the axis of symmetry is the centroid of the shape $(x_c, y_c)$ and the second point is $(x_c \cos(\theta), y_c \sin(\theta))$. In the case of overall symmetry, the axis of symmetry is found by obtaining the orientation axis from the graph representation points. In other words, the graph representation is treated as an image (Figure 4.7).

![Figure 4.7: Axes of Symmetry and Lines of Orientation.](image)

7. The hierarchical structure of the plan is based on its graph representation. The room/space with the most connections to other rooms/spaces or to the exterior is given the highest importance and is drawn with a line whose width is equal in thickness to the number of connections plus one. A space with no connections is drawn with a line whose width thickness is equal to one (Figure 4.8).

![Figure 4.8: Hierarchy of Rooms According to the Number of Neighboring Rooms.](image)

8. The proportional structure of a plan is established by extracting the bounding rectangles for each shape/room. The bounding rectangle is the smallest rectangle that can enclose a given shape. Once the bounding rectangles that correspond to the rooms or spaces of the plan have been established, it is possible to calculate the ratios of their sides. If a shape is composed of rectangular sub-shapes it is broken down into rectangular components. This is done by starting from the centroid of the shape and then “growing” in a rectangular fashion until a boundary point is encountered. The process of growing can be applied to the remaining components of the shape. Then, the ratios of the sides of each rectangular sub-shape are calculated. The concept of the bounding rectangle is meaningless in the case of a non-orthogonal shape. For such shapes the lengths of the sides taken pairwise are used to establish the ratios of the sides. (Figure 4.9).

And now Nicholas Negroponte is suggesting we think of computers as agents capable of completing designed processes or adapting to alternative conditions based upon a contextual framework. Scripting routines already address part of the agent role, and agent-like features can be found in general, non-professional programs such as Kid Pix™ and Inteledraw™.
Figure 4.9: Ratios of the Sides of the Bounding Rectangle for Each Room.

9. The modularity of the plan is based on the proportional structure. This time, however, the rectangles are constrained to fit into a grid, in this case a 10x10 pixel grid. The constraining process is done by snapping each corner of the bounding rectangle to the closest point in the grid. Each rectangle shows in its center its size, which is a multiple of ten (Figure 4.10).

Figure 4.10: Modularity on a 10x10 Grid.

10. Once the information is collected for each plan and each room within the plan, an Image Database can be created. All information extracted from each plan is entered into the Database. Then queries, based on this information, can be made by selecting the criteria for acceptance or rejection. For example, the criterion of shapes having a compactness value of less than 1.5 leads to the selection of the plans shown in Figure 4.11.

Significance and Future Research

The main purposes of this paper were to report work conducted to capture, analyze, and recognize visual information using computers, to create high level descriptions from sensed data, and then to feed this information to CAD systems for further processing. In architecture, numerous benefits can be derived if a computer system for recognizing and interpreting architectural drawings is developed. These benefits can be assigned to the following categories:

1. Efficient input of architectural drawings into CAD systems.
3. Extraction of information which is time consuming and inefficient when performed by humans.
5. Contribution to a better understanding of visual organizations.

In turn, extracting, analyzing, and interpreting the morphological information contained in architectural drawings is likely to lead to a better understanding of the morphology of buildings. The scope of the work that was conducted is not only to recognize morphological information in architectural drawings but to provide a framework that will allow a computer to analyze and classify systematically and efficiently such information. The work that was presented may lead eventually to a computer system that will: (a) provide the user/designer with useful information about drawings, (b) test whether it is possible to have a computer "recognize" compositional principles, and (c) allow the user/designer to manage large databases of images and organize, query, and index them on the basis of morphological attributes. If humans are able to make judgments based on morphological principles, it may be possible to develop tools that will eventually allow similar judgments to be made by computers. Of course, it is not expected that, at the beginning, such judgments will attain the level of complexity of judgments made by humans. Yet, it is expected that, since computers are more powerful than humans in certain areas of processing, such as computation, precision, and speed, they probably will contribute significantly towards making the work of humans more systematic and efficient and therefore more effective.

To date, the work has been confined to extracting knowledge from only the plans of buildings. In the future, it will be necessary to extract knowledge from other types of representations such as elevations, sections, or axonometrics, and then analyze this information further by extracting sets of rules that describe the morphological structure of the building. In addition, more morphological attributes can be extracted, such as axiality, rhythm, balance, and many others.

References


If seeing a computer as tool, environment, or agent opens up all these possibilities, what would happen if we used other kinds of metaphors? For example, we might watch an accelerated version of evolutionary processes in which competing mechanisms, patterns or theories are required to adapt to a series of changes to see which of them survive. Or, we might have forms modify


