NEW GENERATION OF COMPUTER AIDED DESIGN IN SPACE PLANNING METHODS – A SURVEY AND A PROPOSAL

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Abstract. During the past thirty years, the progress of Computer-Aided Design (CAD) has played an important role both in the professional and the academic fields of architectural design. The evolution of this powerful tool has also changed its direction with time as well. When we look back in the evolution history of CAD, space-planning allocation methods, which have been discussed and developed vigorously during the 1970s, became less so after that. Space planning is a critical issue during the architectural design process on which architects spend a large amount of time on early development. This paper will review the space-planning methods during that period and discuss the possibilities of improving these methods, and extending their potential in current computer-aided design methods.

1. The Survey of Space-Planning Program / System and Allocation Methods

In this section, several space-planning programs and allocation methods will be discussed in chronological order. In order to compare the differences, this survey will focus on the following categories:

1. Space parameters: the description and information of the spaces.
2. Space allocation elements: the elements and “forces” that can locate spaces to their proper position.
3. Space-planning methods: the methods that transform the manual space-planning method into a digital process.
4. Representation: the results of these methods and how they are related to architectural design, both two-dimensional and three-dimensional.
1.1. SPACE-PLANNING PROGRAMS

In this category, we can divide space-planning programs into two groups: one group focuses on developing the theory of space-planning, which will contain equations of space relationship descriptions; the other group focuses on developing the methodology of space-planning process in computer programs.

1.1.1. Computer Space-Planning Methods

In traditional architectural design, architects tend to describe space relationships with space adjacency matrix or a space bubble diagram for the client or themselves to understand. (Figure 1) (White, 1986) Furthermore, this adjacency matrix and bubble diagrams become the data for design. By studying the design methods of architects, space-planning procedures have been discovered and organized into methods. These methods gave the developer of a space-planning program a path to follow. There are some similarities in the programs found in the survey:

![Figure 1. Traditional adjacency matrix and space bubble diagram](image)

(1) Space adjacency elements: Different kinds of adjacency matrix were used to fit each program’s needs. (Figure 2) Three elements are shown and considered in an adjacency matrix: space elements, adjacency meanings and adjacency level, which the adjacency meanings are organized and quantified outside the matrix, and been represented as adjacency level of spaces.

These space adjacency elements and the representation of the adjacency level vary between the different programs. Most of the space elements that have been giving different meanings include function, activity, and cost that are related to efficiency, but some of the space-planning programs consider additional issues. The following shows different space elements, adjacency meanings and adjacency level that are being used in these space planning programs.
(i) Space elements: The description of spaces, i.e. living room, bedroom, office, conference room, elevators, mechanical area, etc.

(ii) Adjacency meanings:
General architectural requirement: The need for a pleasant view, need for natural light, production of noise, sensitivity to noise, needs for privacy, and need for proximity to public access. These criteria are used in most of the programs.
Flow efficiency (material, activities and facilities): Relate spaces with similarity of activities, the needs for facilities, and material flow. These elements are directly related to the cost efficiency.
Separation: Offer the decision to not relate in the program.

(ii) Adjacency level:
Represented as yes/no: Simply describe the two spaces’ relationship as “with” or “without” relationships with characters or symbols. (Figure 2a) (Sato and Owen, 1980)
Represented as degree: Describe as low, middle, and high.
Represented as values: describe as 0 – 10, 0 – 99, (-99) – 99, etc. it would be different value range depends on programs need. (Figure 2b) (Fortin, 1978)

(2) Space allocation equations and adjacency meaning equations: After the space allocation equation collects the adjacency values (level), it generates the value with the distance of the spaces and produces a total score. (Equation 1) When all the possibilities are been generated, the allocation equation compares the scores and pick the minimum one (vary depend on different methods) as the optimum, most efficient result for the project. In order to quantify the adjacency values, the allocation equation needs an adjacency meaning equation to generate these adjacency meanings. Instead of using simple adjacency values/levels, some of the methods are more complex that would generate more space adjacency meanings for the
space-planning program to make the result more accurate. Two examples are as follows:

Minimum Score = \( S \) (Distance \times \text{Space Adjacency Value}) \hspace{1cm} (1)

(i) Multiple space meanings generation in single equation: In this method, one complex equation is used to generate many different adjacency meanings and produce an adjacency value for an adjacency matrix. As Figure 3 (Shaviv, 1985), the equation generates many adjacency meanings, such as \( P_{ij}^k \) (hierarchical importance of people \( k \) found in \( i \) and walking to \( j \)), \( N_{ij} \) (number if individuals \( k \) walking from \( i \) to \( j \)), \( F_{ij} \) (frequency of walking of individuals \( k \) between \( i \) and \( j \)), etc.

\[
W_{ij} = A \sum_{k} P_{ij}^k N_{ij}^k F_{ij}^k + B \sum_{1} M_{ij}^{1} N_{ij}^{1} F_{ij}^{1} + C \sum_{m} D_{ij}^{m}
\]

*Figure 3. A complex equation for single matrix*

(ii) Multiple equations generate different space meanings: This method uses different adjacency equations to generate different adjacency meanings. As in the previous method, this program considers many adjacency meanings, but instead of generating them together, it uses different equations and matrices to show the adjacency value. As Figure 4 (Sato and Owen, 1980), three different adjacency meanings are generated by three different equations, \( F_{ij} \) represents flow cost per unit distance considered for components \( i \) and \( j \), \( P_{ij} \) represents a proximity coefficient pairing components \( i \) and \( j \), and \( A_{ij} \) represents a coefficient of similarity between components \( i \) and \( j \).

\[
\begin{align*}
&f_{i,j} = \frac{f_{i,j}^k}{\max_k(f_{i,j}^k)} \\
&\text{where} \\
&f_{i,j} = \sum_k f_{i,j}^k
\end{align*}
\]

*Figure 4. Three different equations for generating different space elements*

(3) Representations: All the results from these programs are two-dimensional. The representations of the results are different according to the goal and the purpose of the program. In this survey, three kinds of space diagrams are produced by the programs:

(i) Space symbol with linear relationship: This representation shows the relationship between spaces with a point or unit symbol and connect them with lines or bubbles. (Figure 5) (Miller, 1970; Sato & Owen, 1980)
(ii) Space symbol with physical relationship: Instead of representing the space relationship with bubbles or lines, this kind of representation shows the spaces relationships by locating them together. This diagram enables the designer to visually understand the physical positions of the spaces. (Figure 6) (Krawczyk, 1973; Teicholz, 1975)

(iii) Quantified space area with physical relationship: This kind of representation includes the consideration of space quantities. The program divides the space as certain quantity unit spaces that can show the correct scale of the total space and locate the space in finer detail. (Figure 7) (Shaviv, 1985) The most recent research shows that the layout of the result can be a space-planning diagram that is close to an actual space layout.
This section includes the following research:
CRAFT – E. S. Buffa & G. L. Armour (1964)
SLAR system – Dale Bryant (1967)
System Building Toward a Protosystem of Unit Generation – Barry Jackson (1968)
General Space Planner (GSP) – Charles E. Eastman (1971)

1.1.2. Computer Space-Planning Process
Except the space-planning methods, the decision-making process is also an important part in the entire design process. Some of the researches in this survey is more focused on the section of decision-making process. We found that the researcher observed the decision process of the architect and attempted to simulate it. Different techniques were developed to improve the result of space planning program. The following techniques show in the order of traditional design process:

(1) Neighbor searching technique: As the traditional design process, architects start a bubble diagram with an important space that many other spaces related to, then start to place in other spaces. In this technique, the highest interactive is chosen after calculating the adjacency values and put it in the middle of the layout space. The other spaces start to be placed in the diagram with the same technique from the center outward.
(2) Switching technique: After the spaces were located, architects would consider the entire space layout and move the spaces to improve the arrangement. This technique is designed to change the result to make it better by comparing certain value calculated by the space allocation equations and switching space locations. This technique can be operated manually and automatically. If the designer is not satisfied with the result that generated by the program, he/she can always change the layout manually and this technique will offer the relatively adjacency score for designer to know either the changed layout is good or bad.

(3) Random technique: After the program produces a result, if the designer still wants some minor improvement, this technique can offer user a certain level of random-changes that differ from the original one. By changing the number-of-switch setting (Krawczyk, 1973), the random technique single-switch the space units number of times, brings out some different results and showing the scores with the results for the designer to compare.

(4) Zoning clustering: Zoning issue is considered when the spaces layout is more proper for several spaces gather as groups by their needs or activity similarities. By recognizing the adjacency matrix (cluster-by-matrix) (Figure 8) or the adjacency values (cluster-by-simplex) (Milne, 1971; Krawczyk, 1973), the spaces will be gathered by this clustering technique. The results of this technique would suggest to designers whether the spaces should gather in one large group or separate to different small groups.

Figure 8. Cluster-by-matrix technique
(5) Hierarchical: A tree structure is frequently used in organizing architectural criteria in a traditional design process. This technique focuses on this idea and has been developed to arrange the space elements hierarchically and be displayed them according to the intensity of characteristic similarity as the semi-lattice diagram. (Figure 9) (Teicholz, 1975; Sato & Owen, 1980)

![Figure 9. Semi-lattice diagrams](image)

This section includes the following research:
- GRASP and SETUP – Eric Teicholz (1975)

1.2. ALLOCATION METHODS IN GRAPHICAL MANNER

The programs in this category are more focused on developing the space allocating method in a graphical manner, which describes more detail about how the results are shown and improved.

In the space-planning program, spaces and their relationships will be represented as different graphical figures, the space diagrams. These diagrams tell users about the results from the program. The accuracy of the diagram will affect user’s decisions; furthermore, will affect the efficiency of the programs. The research in this section demonstrates different aspects that can improve the graphical representation of the space relationship. As previous research, these allocation methods analyze designer’s space-arranging and re-arranging technique and transform them into certain rules. Four different methods are covered in this survey:

1. Virtual grid searching method:

This allocation program represents a space as a certain size two-dimensional square and the locating environment as a area of grids. By using this allocation program, the space squares start to be located by certain rules. First, the program calculates the relationship values of the spaces and finds the ”neighbor” for certain space squares. When the neighbor is found, the program finds the “centroid” of the space squares and locates the neighbor
on a proper position (grid). *(Figures 10)* (Mitchell, 1971) This method is popularly used in many space-planning programs.

![Grid searching method](image)

*Figure 10. Grid searching method*

(2) Bubble diagram simulation:
This program is based on the similar space-planning rule with the previous one, but represents the result as a traditional bubble diagram. Because of the educational purpose (Fortin, 1978), this representation of this program simply shows the space relationships with bubbles (spaces) and strings (connections between spaces) *(Figure 11)*, which is used in traditional architectural methods.

![Bubble diagram simulation](image)

*Figure 11. The result of bubble diagram simulation*

(3) Interactive Space Layout:
By observing the problems from the existing space-planning program, Ruch proposes a graphical improvement for the space-allocation method (Ruch, 1978). The proposal describes the result of the space-planning program in three different ways: network diagram, bubble diagram, and schematic plan *(Figure 12)*. Because of the different virtual relationship between these layouts, the program can evaluate them and make space-layout suggestions for the designer. This method helps the user of space-planning program to realize the importance of space quantity in space-planning program.
(4) Physically Based Space modification

Different from the manual change for space size in other space-planning programs, this method applies the physics of motion to the process of the space allocation program (Arvin and House, 1999). This method defined the virtual space in the computer with two properties: topological and geometric. Topological objectives influence the location of individual spaces, affecting how one space relates to another. Geometric objectives influence the size and shape of space boundaries, affecting the dimensions of individual walls. (Figure 13) With this different approach, the allocation program can arrange the spaces without being limited by space size and dimension.

This section includes the following research:
BUCKET – Gilles Fortin (1978)
Interactive Space Layout: A Graphic Theoretical Approach – Julia Ruch (1978)
1.3. EVALUATION

In this survey, different aspects of space-planning methods have been discussed. This previous research is the foundation for the future evolution of the space-planning programs. It also shows the limitation of computer-aided design in that period and indicates potential improvements. There are two possible improvements that were uncovered in this survey: one is the space adjacency element, the other is the representation of the result of a space-planning program.

(1) Space adjacency elements as related with the environment: We have seen many different descriptions about space adjacency elements. Most of them discuss the inner-space relationships, which can only create the space diagram or schematic plan that describe the relationships and needs for the inner spaces. Some of the spaces can be related to the outside environment and develop an initial building envelope.

(2) Three-dimensional spatial diagram: The two-dimensional space diagrams that are created by space-planning programs can describe the essence of a space plan, but because of the limitation of being plan oriented, the relationships between different floors cannot be included in the same diagram, nor the form of the spaces. By incorporating and modifying existing research, three-dimensional space diagram can be created to show space relationships more clearly, and even provide a conceptual form for the building.

2. New Generation of Space-Planning

When traditional space-planning methods were analyzed, the potential of developing CAD system for space planning is still worthy of research. In my current research, after combining the past research and new ideas, a diagram of a new space planning program is proposed: Space Planning Design Assistant (SPDA). (Figure 14) In this diagram, several new concepts are added in the space adjacency area: Space Character and an Architectural Form Element.
According to the categories in the survey, space adjacency elements can be described in a number of different ways. If we consider a space is a person, and a group of people who gather according to similar requirements, we can then assume every space has its own “space character”, either in very abstract or practical sense, or both. In traditional design methods, a designer groups spaces that have similar functions or similar needs together (Figure 15) (White, 1975), or places spaces with special needs to certain places (Figure 16). Those functions and needs can be transformed into space characters in a space-planning program, which will gathering or place them automatically.

Figure 14. SPDA Diagram

The need for privacy

Figure 15. Similar needs for space groups
Besides the inter-relationships of the spaces, space element can also be used in the site zoning and planning purpose. In this level, the existing space groups will find their own position that followed their own special requirement. *(Figure 17)* (White, 1975) This kind of adjacency element not only can represent functions and needs of spaces, but also represent the “force” that can form the particular shape that in designers mind or emerge to the environment, we identify it the Architectural Form Element. *(Figure 18)* This architectural form element not only can form the certain shape in two-dimensional, it is very likely to be the important element for three-dimensional representation.
The representations in past research show that the results stay in two-dimensional space relationship diagrams. By taking advantage of today’s computer resources, three-dimensional diagrams can be produced to show clearer space relationships to the designer. In my current research, the possibility of three-dimensional form representation was studied. \( \text{(Figure 19)} \) With a certain rules and organization, three-dimensional diagrams are possible to create by a well-organized space-planning program. Furthermore, the initial building shape can be suggested in certain level of detail. It will give the designer additional ideas about the architectural form, not only in a conceptual stage, but also offering a very functional form.

\[ \text{Figure 19. Possible three-dimensional representations} \]

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METHODS – A SURVEY AND A PROPOSAL

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