PREDICTING ARCHITECTS' PLAN PREFERENCES

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1.0 ABSTRACT

This paper describes the logic testing for an expert system module that looks at an inprocess CAD drawing, identifies the plan type and recommends an alternative plan that is consistent with the designer's preferences, but has better energy performance. The knowledge base was developed in the form of a morphological matrix. The rationale, construction and testing of this knowledge base is described.

2.0 SUMMARY OF CONCLUSION

- The revised matrix correctly predicted users' choices as shown in illustration 2.0 - 1

Avg. # correct	**Most** **Similar**	Next MostSim	NextNext MostSim	NextNext LeastSim	Next LeastSim	**Least** **Similar**
3rd phase	48.0%	62.3%	72.2%	8.2%	17.8%	31.2%
Ref. Freq.	4.5%	4.8%	5.0%	5.3%	5.6%	5.9%

(Reference frequency refers to that probability of suggesting the same configuration by random chance, assuming that the most similar configuration has a 1/22 chance of being chosen, and the least similar configuration has a 1/17 chance of being chosen.)

Figure 2.0 - 1
Most and Least Similar Responses

- The increased percentage of correct answers demonstrated that the matrix could be calibrated to a user group to increase its predictive power.
- Doing the design problem first changed the users' perceptions of what schemes were similar and least similar.
- Most of the designs clustered around compact schemes and blob small room arrangements, confirming our hypothesis that strong and weak poles exist on both axes.
- A courtyard arrangement should be added to the small room axis.
- The matrix is better at predicting similar arrangements than dissimilar arrangements.

We feel that the matrix can be further refined to increase its predictive power. The matrix format can apply to the entire range of architectural issues, not just energy. In addition, our experience using this method suggests that it will be possible to link together matrices in a range of scales from site to component.

3.0 INTRODUCTION

The work described in this paper was part of a larger project to develop a prototype expert system that would help architects design energy efficient buildings. Our particular part was to develop a module that would help architects make plan configurations and select building components and materials. This paper addresses the plan configuration issues exclusively. The prototype expert system was limited to a particular building program and climate–a rural community center in a hot-arid climate–and was built on top of a commercial CAD system.

3.1 WHY PREDICT ARCHITECTS' PLAN PREFERENCES?

The basic motivation for predicting a designer's preference is to be able to suggest improvements to a building design that the designer will accept because they are consistent with her or his design goals. In our case we wanted to be able to look at an inprocess CAD drawing, identify its plan and suggest another plan that the designer would like but that would have the potential for better energy performance.

3.2 A MATRIX KNOWLEDGE BASE

In order to predict a designer's preferences, we first had to establish the universe of possible plan configurations. Since this part of the expert system was intended to be used in the schematic part of the design process, plan configurations could be simplified and kept to a fairly small number. We developed a matrix whose axes displayed the spectrum of possible configurations for the scheme–extended or compact, arrangements for the auditorium and the small rooms, five basic organizations for the small rooms, and the possible lobby/entrance locations. These axes in turn produced 23 possible plans, as shown in cells A1 – F5, figure 2.2 - 9. Because each cell is generated from the axes of the matrix, the rows and columns that intersect to form any particular cell can be used to infer designers' preferences for other cells. Our basic procedure, then, was to use the inprocess CAD drawing to identify the cell most similar to the designer's plan and then move along the rows and columns until we found a similar plan that had better energy performance.

3.3 METHOD OF INVESTIGATION

The configuration of the matrix knowledge base was tested using architects and architecture students. In the first test the volunteers were given one plan configuration, (one matrix cell) in diagram form and asked to identify, from a randomly arranged group of 22, which three plan diagrams were most similar and which three were most different from the plan diagram they were given. In the second test the volunteers were asked to arrange the small room organizations in a logical sequence and to suggest other arrangements. In the third test the volunteers were asked to first design the building, and then find their building design in the group of 23 plan configurations. They were also asked to repeat test one, finding similar and dissimilar plans for each cell.

4.0 MORPHOLOGICAL MATRIX KNOWLEDGE BASE

This section describes the rationale for using a morphological matrix to develop a universe of plans and arrange them in an order that would help reveal architects' plan preferences. It also describes the rules developed for traversing the matrix.

4.1 RATIONALE FOR A MATRIX KNOWLEDGE BASE

The research team had experience designing a community center using a participatory design procedure (Brown, 1980). The design process, which consisted of showing the community center's design committee a structured series of design alternatives, had been carefully documented and was available to us.

In this case a device called a morphological matrix was used to generate alternatives so that the committee could understand what options were available to them in community center design. A morphological matrix uses horizontal and vertical axes to display attributes which are then combined in the cells formed by the intersection of the two axis. For example in illustration 4.1 - 1 attribute "A" is combined with attribute "1" to produce "A1".

	A	B	
1	A1	B1	
2	A2	B2	

Figure 4.1 - 1 A Basic Matrix

Selecting what elements should go along the axes is very important and takes considerable experience to develop. The axes should be the generators of the design, that is, the key elements that determine the character of the design.

In our work with user groups we have noticed a phenomena about how people select their second design choices. Once they have made a first choice, their second choice is often along either the row or column common to the cell they selected for their first design. See Figure 4.1 - 2

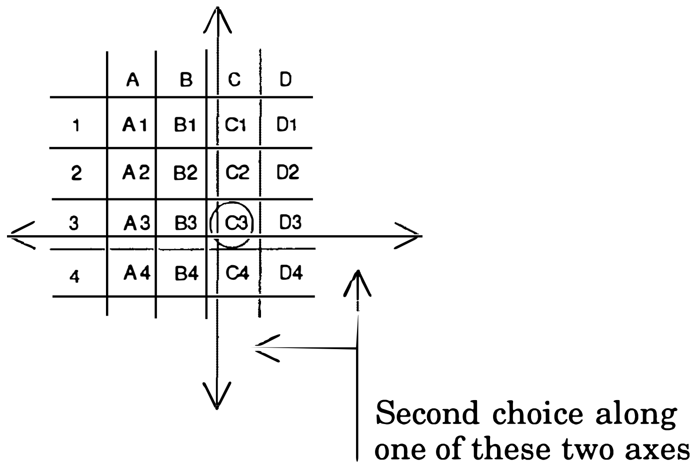

Figure 4.1 - 2 Subsequent Choices Within a Matrix

It was clear from talking to individuals in the user design committee, that in making their second choice the users were responding to the primary generators that created their first choice design. For example, if C (fig. 4.1 - 2) was the most important generator, they would pick C1, C2, or C4 as the second choice design.

This realization formed the basis for a method of selecting a plan similar to the one a designer was working on. If we could determine which cell a designer was working on we could, by moving along a column or row, have a better chance of finding an alternate plan, that the designer would like than either picking cells randomly or solely on the basis of energy performance.

4.2 MATRIX CONSTRUCTION

The program elements for the community center were an auditorium/library at 1000 sf; a lobby, at 350 sf; 2 toilets, at 150 sf each; and 5 offices, at 140 sf each. We felt that these program elements fell into two primary groups: the auditorium/library, which was the focus of the community center, and the small rooms, which played a supporting role to the auditorium/library. So the primary axes of the matrix should deal with these two groups and their relationships to each other.

Relationship of the Auditorium to the Small Rooms

The auditorium and the small rooms have two primary relationships: 1) Compact arrangements in which the small rooms are located near the auditorium for functional proximity or when a building with minimum perimeter is desired for reduced cost or reduced heat loss; and 2) Extended arrangements in which the smallest rooms are located in wings in order to increase surface area for solar gain or daylight, to express programmatic differences in function, to form exterior spaces or to generate elongated faces to front onto roads or open spaces.

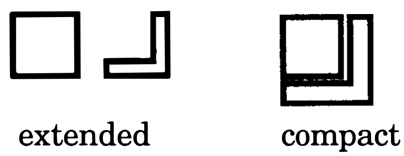

Figure 4.2 - 1
Proximity of Rooms to Auditorium

Small Room Arrangement

The small rooms (including the WC's) are grouped together and considered as one mass without differentiation. The small room organizations are the blob, single bar, double bar, ell, and U. Tee's and crosses were considered but not used because there weren't enough small rooms to make these configurations very likely. Each small room arrangement implies a circulation; the blob would be double loaded, and the bar, 2 bar, ell and U would be single loaded, with outside and inside corridors possible in the ell and U.

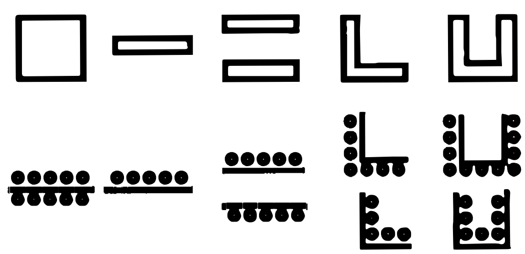

Figure 4.2 - 2 Small Room Arrangement Types

While the circulation is implied and the diagrams sized to include circulation, it is not shown in the matrix cells. The designer is imagined to select one of the small rooms configuration because

1) of proximity relations between the small rooms–close together = blob, and separated from each other = all the others; or
2) the desire to form a defined outside space=ell and U; or
3) proximity to the auditorium space = bar, 2 bar, ell, U; or
4) building massing i.e., elongated = bar, 2 bar; compact = 2 bar, ell, U; or
5) a combination of 1 through 4.

Relationship of the Lobby to the Auditorium and Small Rooms.

The lobby and its related entrance is seen as the third important architectural variable needed to generate the generically different plans that are possible for the community center. The possible lobby locations are between the auditorium and the small rooms in the middle of the small rooms, or at the end of the small rooms. (All these variations assume one primary entrance that serves all spaces.) A designer might place the lobby between the small rooms and the auditorium to make the lobby close to the auditorium, or to separate the program elements for clarity of expression. Alternately, the designer might put the entry in the middle of the small rooms to separate the WCs from the offices and associate them with the auditorium, or to create a facade with a central entry focus, or to decrease total circulation. Or, the designer might put the lobby at the end of the small rooms thinking that visitors might come to the offices and conference rooms more often than to the auditorium or to create an extended promenade to prolong the entrance sequence to the auditorium.

Ranking Matrix Cells

Designs may be ranked by energy performance if data is available in a format that can be represented by a single performance number such as Btu/hr/sf/yr. If energy performance is represented by a range having to do with variations in insulation level, amount of mass, etc., a ranking could be achieved by using the average of the range.

The plan matrix was organized so that there were primary, secondary, and tertiary generators. The primary generators are what we think are the most important or most fundamental variables in the matrix. In our case the primary generator is the relation of the small rooms to the auditorium/library–whether extended or compact. The secondary generator is the small room arrangement, and the tertiary is the relation of the lobby to the small rooms and auditorium/ library. This distinction allows us to determine which better energy performing options to pick first–those along a column or along a row.

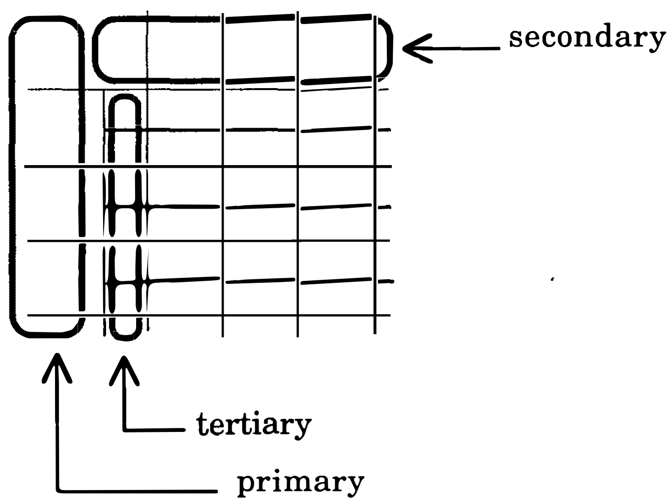

Figure 4.2 - 3
Primary, Secondary and Tertiary Generators of Form

Each axis should also represent a range, with each end being a pole and the intermediate points representing a progression from one pole to the other. An attempt should be made to capture the ends of the range and the important intermediate steps. (see fig. 4.2 - 4.) There are of course many subtle variations between each step.

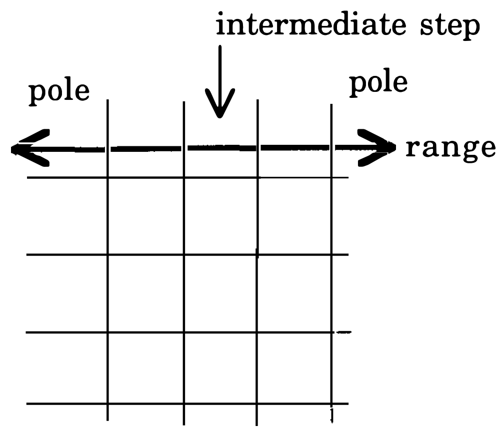

Figure 4.2 - 4
Establishing a Range

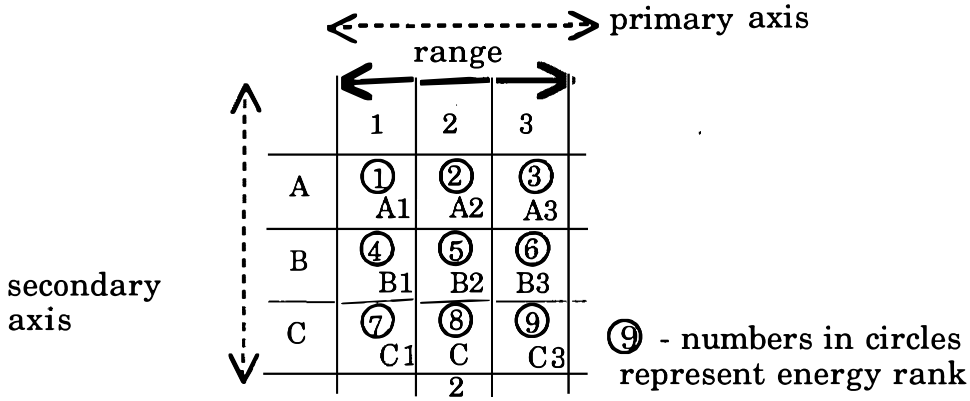

Figure 4.2 - 5
Cell Selection by Energy Rank

If the designer were to draw cell C3 first, we could then infer any of the following:

- The cell the designer would be mostly likely to like (most similar) with better energy performance would be B3.
- The cell the designer would be 2nd most likely to choose with better energy performance would be A3.
- The cell the designer would be 3rd most likely to choose with better energy performance would be C2.
- The cell the designer would be 4th most likely to choose with better energy performance would be C1.

- The cell most different from C3 is A1, as it is at the opposite poles of both axes from the selected cell.
- The next most opposite is B1, since it has the greatest distance along the primary axis.
- The next most opposite cell from C3 is A2.
- The next most opposite is B2.

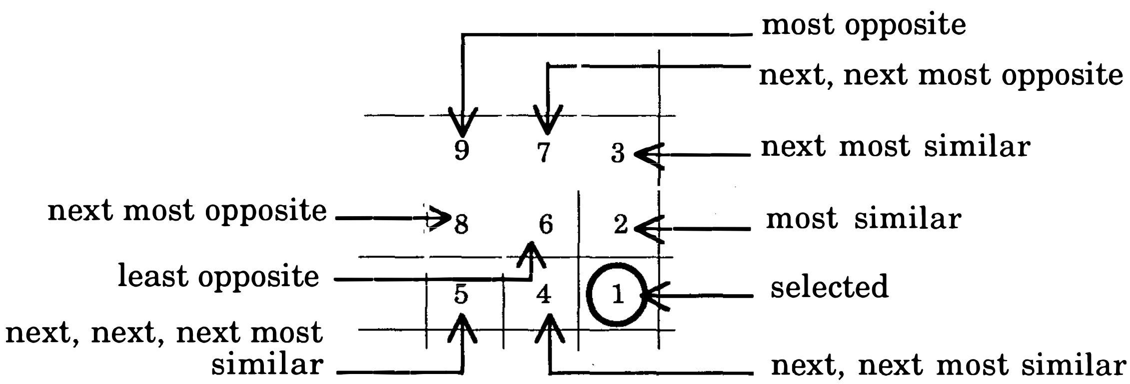

Figure 4.2 - 6
Arrangement of Cells which are Most Like or Most Unlike Initial Cell Selection

In order to address the problem of cells selected in mid-range, "strong" and "weak" poles are established. A strong pole would be the extreme that would generate the most acceptable solutions when the problem was done by a group of designers.

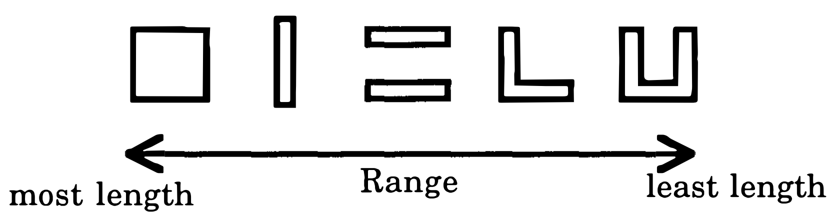

Figure 4.2 - 7
Range of Choices According to Length

Using the small rooms in the plan as an example, the least length or blob would be the strong pole with the most design solutions clustering toward that end. Part of developing the knowledge base using matrices would be calibrating the strong and weak poles of an axis by establishing user preference.

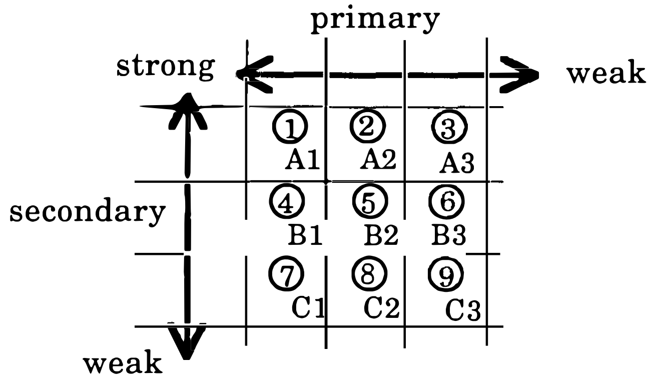

Figure 4.2 - 8
Matrix Showing Strong to Weak Ranges

Assuming cell B2 is selected:

1. Cell A2 would be the most similar because it lies on the column related to the primary axis and moves in the direction of strong pole on the secondary axis and is a better performer.
2. C2 would be the next most similar, but it is a poorer energy performer and would not be selected.
3. B1 would be the most similar, proceeding along the secondary axis row in the strong direction of the primary axis.

Using the techniques described in this section we developed the plan matrix shown in Figure 2.2-9. This matrix, along with methods for selecting similar and different designs form the knowledge base. The cells A1 through C1 and F2 through F5 are not present because such combinations are nonsensical. One would not design an extended scheme using a compact arrangement of small rooms (A1, B1, C1). Conversely, all arrangements using a blob of small rooms are compact by definition. Likewise, cells F2-F5 are redundant to cells D2-D5.

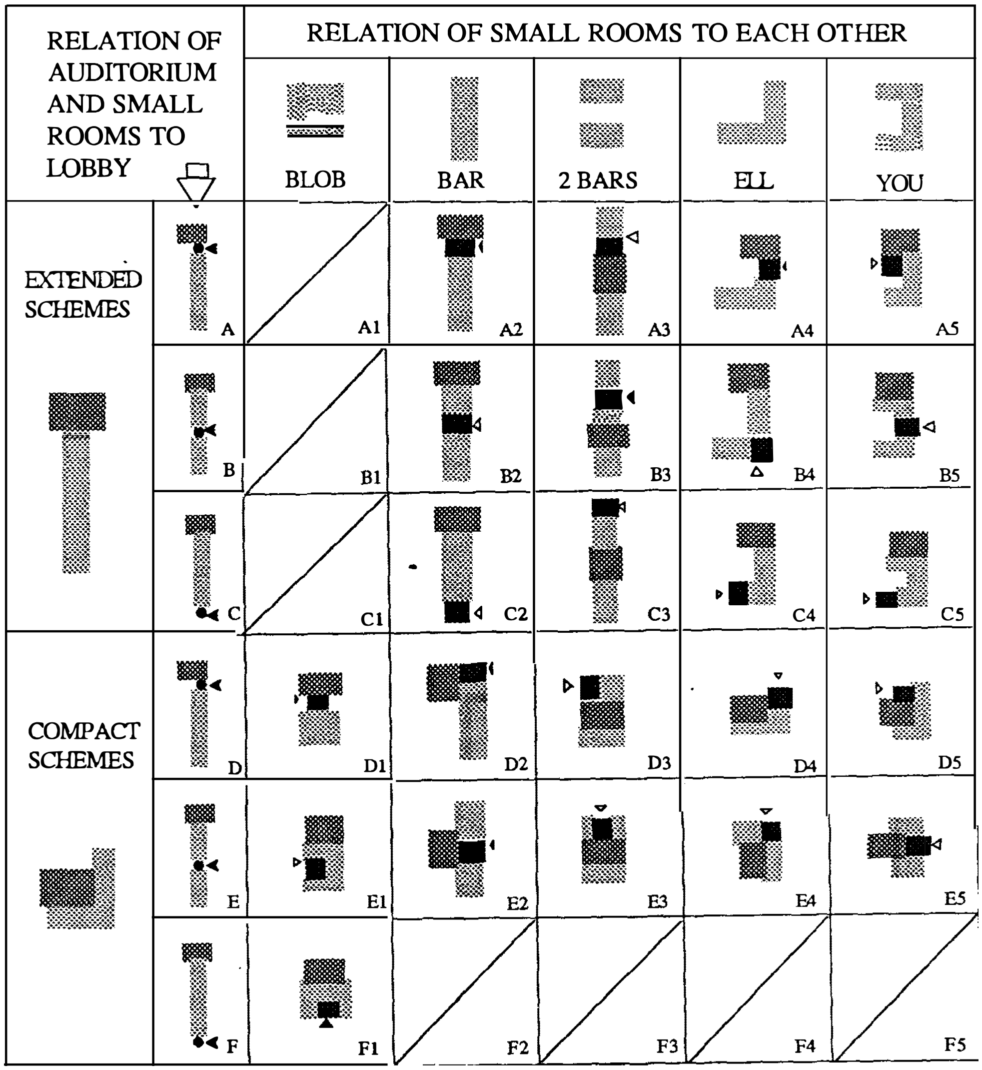

Figure 4.2 - 9
Plan Morphologies for a Rural Community Center

4.3 TRAVERSING THE MATRIX

Once the Morphological Matrix is set up (fig. 4.2-9), we have to define similarity and difference (of designs) in terms of this matrix. In order to do this the matrix must be divided into two separate matrices: one containing rows A through C (the extended schemes), and the other containing rows D through F (the compact schemes). This division accommodates the three dimensions of the design morphology (in order of importance: the scheme, the relation of small rooms to each other, and the relation of the auditorium and the small rooms to the lobby).

We also introduce the notions of strength and weakness–the stronger the design, the more likely that design will be chosen by the average designer. We have hypothesized that the more compact schemes are the strongest, so the cell F1 would contain the strongest design (see Figure 4.3 -1). Given equal distance of a cell from the reference cell (the cell that represents the configuration of the user's design), the tie is resolved in favor of the strongest design.

In order to traverse the matrix whenever a reference cell is chosen (either the initial choice or the accepting of a proposal), the system sets up some vectors to contain the numbers of the rows and columns in the order that they should be visited. Of course there are two sets of rows: the first set is used to hold the rows that include the row that the reference cell is in; the second contains the other rows.

A simple traversal of the matrix (most similar designs first) is now possible. Given the row and column in which the reference cell is located, the first set of rows is used to traverse one column in one-half of the matrix. Then the next column in the column vector is used, and once again the first set of rows is used to go through that column. After all the columns are traversed in that half of the matrix, the next set of rows is used, and the other half of the matrix is traversed.

An example will help. Suppose that the reference cell is A2. The first row vector would contain A, B, and C; the second D, E, and F. The column vector would contain 2, 1 (tie resolved in favor of strength), 3, 4, 5. So the order of traversal would be as depicted, starting in the top half of the matrix and proceeding to the lower half (see Figure 4.3 - 1). Note that some cells are skipped because they are empty.

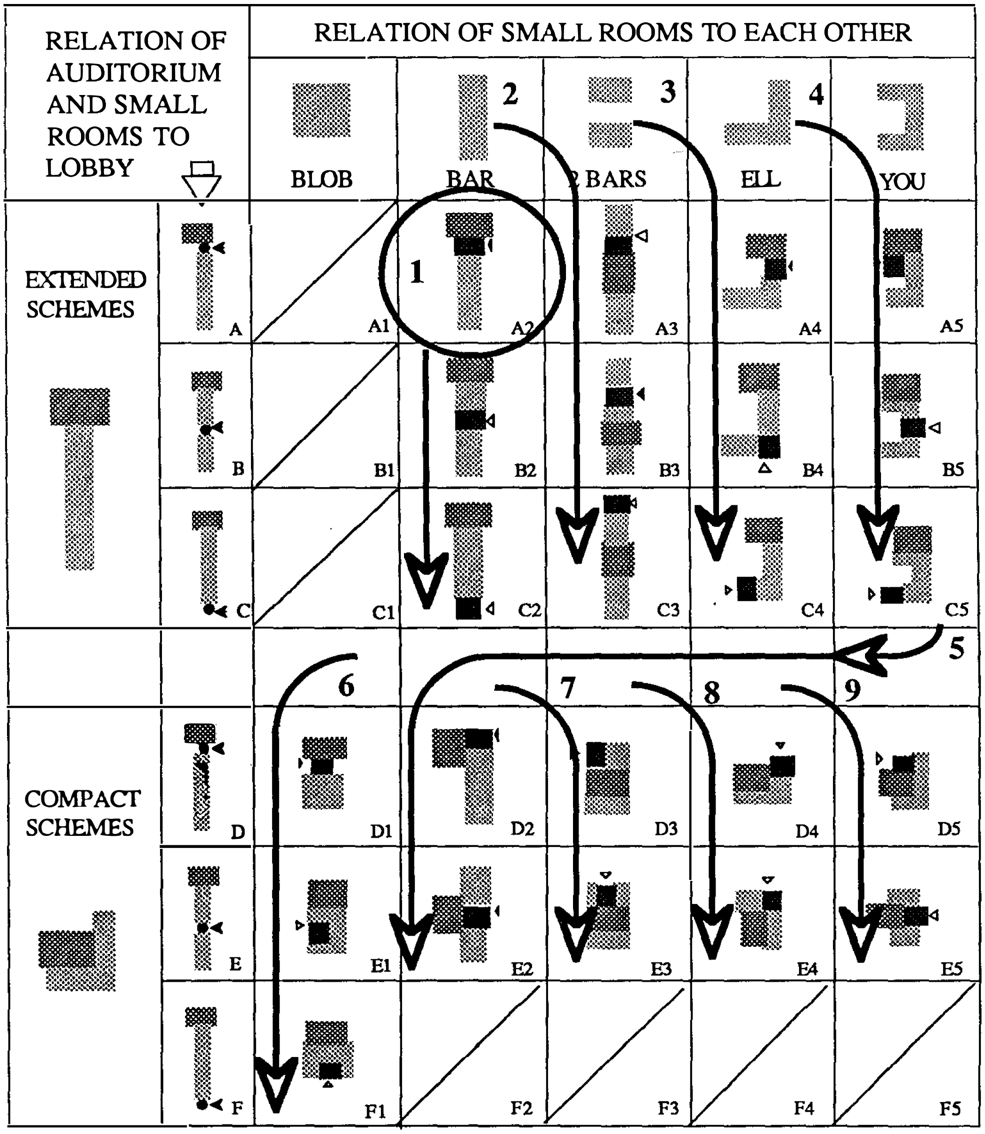

Figure 4.3 - 1
Traversing the Morphological Matrix Utilizing the Strong Pole of the Axes

Some things are worth noting. First, the reference cell being in the middle of a row or column presents no difficulty–as shown in the order of the columns, 2 , 1, 3. We merely fan out from where the reference cell is, taking strong before weak designs in resolving ties in distance. Second, the row and column vectors can be used to find the most different designs by traversing the row/column vectors in reverse order (and of course starting with the second set of rows); only a different set of position markers are needed to keep the current position of a search for different designs. And finally, by preprocessing the vectors to hold the row and column numbers, we can do some explicit mapping based on the row and column of the reference cell. The algorithm is simple to program and runs efficiently.

5.0 EVALUATING THE ORGANIZATION OF DOMAIN KNOWLEDGE: USER VERIFICATION OF MATRIX RELATIONSHIPS

Evaluating the matrix occurred in three phases. The initial phase focused on designing and testing the evaluation procedures, and obtaining qualitative evaluations of the matrix itself. In the second phase, the changes to the matrix implied by the results of the first phase were investigated and implemented, and the evaluative materials and processes were also redesigned. The third phase consisted of investigating the relations in the reconfigured matrix, and evaluating that quantitative data.

5.1 FIRST PHASE: DESIGN AND EVALUATION OF TEST PROCESSES, MATERIALS AND MATRIX RELATIONSHIPS

Following design and internal review of the evaluative materials and processes, a group of volunteer users completed 99 evaluations. The evaluation process consisted of showing subjects a single plan configuration and asking them to choose six other plan configurations from the twenty-two remaining (randomly arranged) plan configurations. By specifying configurations which were relatively similar or not similar to the given configuration, the subject established an hierarchical vector having the given cell at one extreme and the configuration thought to be least similar at the other extreme.

	•	•	•	...•...	•	•	•
Given Cell	**Most Similar**	Next Most Similar	Next Next Most Similar	**and so on**	Next Next Least Similar	Next Least Similar	**Least Similar**

Subjects were also asked to indicate reasons why they chose a particular configuration for a particular place in the vector.

The data returned by the subjects in the first phase indicated that some subjects used criteria other than the matrix's axes and poles to generate similar and not similar relations, and that the columnar progression of the original matrix could be improved. The graphic representations of some diagrams also focused too much attention on the lobby (our presumed tertiary generator of form).

The criteria used by subjects to generate relations included using small room configurations as the primary criterion (instead of the compact / extended scheme type), and using the tertiary criterion (lobby location) as a secondary criterion. Other criteria indicated by subjects disregarded or combined the matrix conventional axial differentiation in unexpected ways. These other generators of formal quality included:

- whether the small rooms were on one side of the auditorium; or on more than one side of the auditorium;
- whether the small rooms were on two sides of the auditorium or three;
- if rooms were on two sides of the auditorium, whether the small rooms were on adjacent or opposite sides of the auditorium;
- whether the overall configurations were asymmetrical (e.g.,an extended ell), or symmetrical about one axis, or symmetrical about two axes.
- whether the overall configuration implied a semi-enclosed outdoor room (courtyard) or not;
- whether the lobby was either close to the auditorium (i.e, adjacent to the auditorium or among the small rooms), or not close to the auditorium (i.e., among the small rooms or separated from the auditorium by all the small rooms).

These other criteria were used to justify both similar and dissimilar choices and were generally exclusive of all other types. For example, if a scheme had rooms on only one side of the auditorium, all schemes which had rooms on more than one side of the auditorium were dissimilar, regardless of whether they were compact or extended.

In the case of the columnar progression, the data implied that the double bar column should not be adjacent to the bar column. The double bar configurations were seldom chosen as most similar to those of either the bar configurations or the ell configurations; in fact, they were often chosen as least similar. This observation, combined with the frequent mention of whether rooms were on two or more sides of the auditorium, indicated the progression of columns (small room types) in the matrix was not congruent with user expectations.

Finally, the diagrammatic representations of certain configurations were confusing: the method of indicating lobby location in compact schemes was especially subject to misinterpretation.

At the conclusion of the first evaluative phase, it was hypothesized that the subjects' reliance upon synthetic criteria to generate similar and not similar configurations might indicate their understanding of the design was limited because they had not actively engaged the design. This hypothesis would be tested in the third phase by asking subjects to actually design and compare their design to the configurations used in the matrix. The columnar progression of the matrix was clearly problematic and required further investigation. And finally, the diagrammatic qualities of some configurations required revision.

5.2 SECOND PHASE: IMPROVING THE EVALUATIVE MATERIALS AND RECONFIGURING THE MATRIX

The second phase of evaluating the matrix addressed the issue of how the columns in the matrix should be ordered. Fifteen subjects were given randomly arranged diagrammatic representations of the small room configurations and asked to arrange the diagrams into any logical sequences or groups, and give the reasons or rules that guided those formations. They were also asked to indicate where discontinuities (if any) occurred, and describe configurations that might bridge those gaps.

The small room progressions assembled by the subjects consistently indicated the bar - ell - U (or the U - ell - bar) sequence was a set. Whether this subgroup initiated, completed or was in the middle of a sequence, it occurred in almost all (14 of 15) of the responses.

In contrast, the blob and double bar configurations occurred in less consistent relations to the other three. The double bar configurations were seldom placed adjacent to the bar configurations (as in the original matrix), but were often found at the extreme of a sequence–often either opposite the blob or adjacent to it. This finding closely paralleled the findings of the first phase. Three people directly addressed the blob - double bar relation by indicating that the sequence was recursive, and diagramed the relationship sequence using a circular format (instead of a linear format). In those cases, the double bar was almost invariably located between the blob and the bar. Note that the sequence can be reversed (viewed as an anti-clockwise progression).

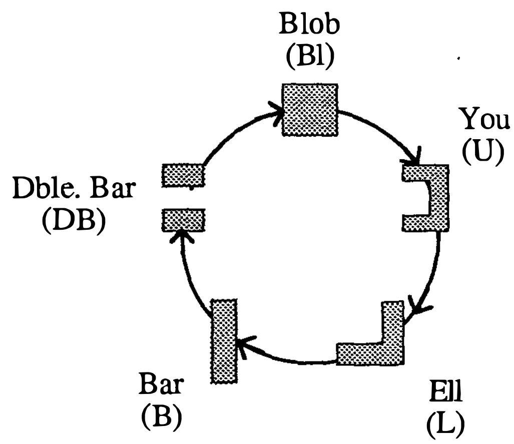

Figure 5.2 - 1
Sequential Arrangements of Small Rooms

The relationships of the blob and double bar to each other and to the bar - ell - U set raised the issue of what principles or notions people used to order their sets. Many indicated they used a continuous process of transformation, where forms were incrementally changed. These progressive transformations could be either subtractive or additive, depending on whether the sequence were read left to right or right to left (clockwise or anti-clockwise). But the sequence usually included:

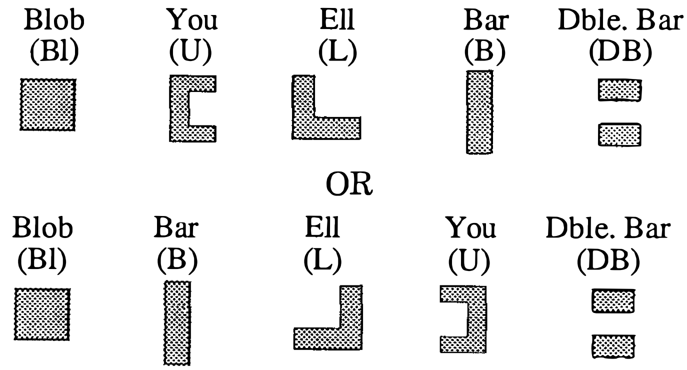

Figure 5.2 - 2
Small Room (Columnar) Progressions Favored by Users

Again, this insight paralleled earlier findings, and so the small room progression (arrangement of columns) in the matrix was changed to utilize the blob - bar - ell - U - double bar.

Some respondents also indicated that other small room configurations were possible, and suggested the following diagrams.

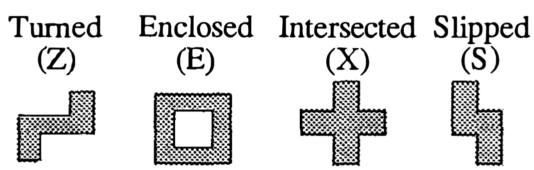

Figure 5.2 - 3
Additional Small Room Arrangements Suggested by Users

Surprisingly, the "Tee" configuration was not suggested in this phase. However, again we did not use these sets of configurations in revising the matrix for two reasons:

- The turned, intersected and slipped schemes could probably be mapped into one of the existing configurations, depending on actual configuration.
- The enclosed scheme was not probable, given the spatial limitations of the design program.

Therefore, the second phase of the evaluation concluded with formal and diagrammatic revisions of the matrix, which still contained only the original 23 configurations. See Figure 5.2 - 4.

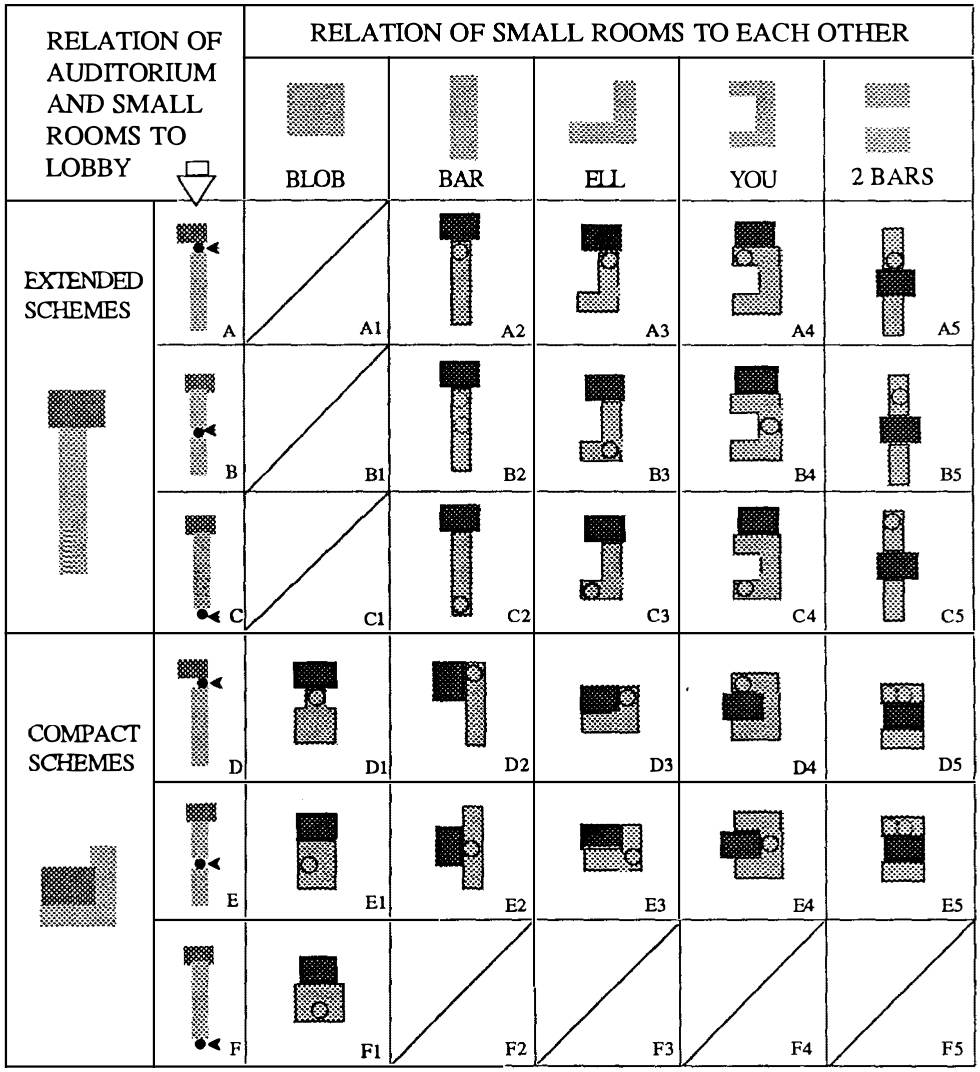

Figure 5.2- 4
Matrix as Revised at the End of the Second Phase

5.3 THIRD PHASE: DESIGN PROBLEM AND CONFIGURATIONS RELATIONSHIPS

In the third phase of the evaluative process, 18 subjects engaged the design problem (i.e., designed the building using a given program) before establishing the vectors. This additional phase allowed the subjects to develop, utilize, and evaluate generative criteria. The design phase would also help determine if the axes had strong or weak poles (i.e., if the matrix did indeed have a zone where designs would be more prevalent), which the matrix uses to generate the similar/ not similar extremes of vectors.

Following the design phase, the designers were asked to match their design to a configuration used in the matrix, if possible (the configurations were randomly arranged). A return of "no match" was allowed to be an acceptable response. Following the design and match exercises, they were shown all 23 configurations (one at a time), and asked to establish the ends of the traversal vectors by choosing the three configurations which were relatively most similar and the three configurations which were relatively least similar to the given configuration from the twenty two other configurations. They were not shown the revised matrix, and the configurations remained randomly arranged; they were again asked to note reasons for their selections.

Design Phase Results

Eighteen designs were completed by the subjects; 12 of the 18 designs clustered near the compact edges of the matrix. Five subjects claimed none of the configurations matched their designs, and four of those claims were true: the designers had created two kinds of configurations thought unlikely, given the design program. The two new configurations were U's enclosing a courtyard; and compact tee's. The fifth scheme that did not match a matrix configuration would probably have been correctly classified by the subject had the diagram of cell D1 been less graphically ambiguous.

Of the 18 designs returned, the matrix would have predicted 13 correctly; four of the other five were "Not Matched" designs. The fifth unmatched design was a courtyard scheme with rooms touching three sides of the auditorium which the matrix would have interpreted it as a compact U. The matrix would have interpreted one U scheme as a compact ell and the other a compact double bar, and would have been wrong. It also would have mapped the compact tees into compact ells. The reason the matrix would have made these mistakes is clear when examining the designs: the designers have attached the store room to the auditorium, and clearly did not count it as part of the small room set when they drew the diagram of their design. The matrix, however, would have considered it to be part of the small room set. This kind of differentiation is part of a larger issue we faced in designing the matrix: how to resolve ambiguous conditions based on functional, not geometric relations between rooms; and as a special subset of that issue, how to specify the quantitative geometric criteria which can consistently define courtyards.

Given that the designers had matched their own design to one of the matrix configurations, the matrix choices of most similar and least similar configurations were compared to the designers' choices. In 11 of those 12 cases where designer and matrix agreed on the interpretation of the design, the matrix would have suggested the same configurations as most similar and next most similar–establishing the progression at one end of the vector, given the reference configuration. The matrix would have suggested the same configurations as least similar in 6 of the 12 cases–and even in those cases, the congruence extended only to row or column, and not to exact cell.

Vector Determination

The central function of the matrix is to suggest schemes which are either similar or not similar to a given design. In comparing the matrix's suggestions to those made by human designers, we noted that in general there was more agreement between the two when suggesting similar schemes than when suggesting not similar schemes. However, in either case the matrix suggestions were much closer to user expectations than were random suggestions. The evaluations revealed that the matrix chose the same configuration as most similar to the reference configuration as at least half of the subjects for 14 of the 23 configurations. In virtually all of the evaluations, the matrix suggested the same most similar configurations as 72% of the users within three suggestions. In contrast, the matrix suggested the same least similar configuration chosen by users only 31% of the time, even with three possible suggestions.

Total	**Most Similar**	Next MostSim	NextNext MostSim	NextNext LeastSim	Next LeastSim	**Least Similar**
correct resp.	131/273	170/273	197/273	22/269	48/269	84/269
Avg. # correct	48.0%	62.3%	72.2%	8.2%	17.8%	31.2%
Ref. Freq.	4.5%	4.8%	5.0%	5.3%	5.6%	5.9%

(Reference frequency refers to that probability of suggesting the same configuration by random chance, assuming that the most similar configuration has a 1/22 chance of being chosen, and the least similar configuration has a 1/17 chance of being chosen.)

Figure 5.3 - 1
Summary of Most Similar Responses

At a finer level of analysis, the matrix would have satisfied at least half of the subjects in suggesting most similar configurations for 22/23 (95.6%) reference configurations, and 19/23 (82.6%) least similar configurations according to primary criterion only. The matrix and at least half of the subjects suggested the same most similar configurations 15/23 (65.2%) and 10/23 (43.5%) least similar configurations according to both primary and secondary criteria. When all three criteria are considered, 12/23 (52.2%) of the most similar and 2/23 (8.7%) of the least similar configurations exhibit the same congruence. Two of the configurations (8.7%) met all three criteria in both similar and not similar modes, and seven of the configurations (30.4%) met both primary and secondary criteria in both similar and not similar modes.

The design task of the third phase confirmed the notion of strong and weak poles on the axes used by the matrix to generate vectors and suggest alternative configurations. The ability of the building program to accommodate courtyard schemes indicates the matrix should be revised again to include those configurations. Analysis of the individual returns indicated that while the matrix was better at suggesting similar configurations than not similar configurations, in general the matrix made suggestions in accordance with user expectations.

The matrix has proved capable of organizing domain knowledge and accommodating revisions to match user expectations. The rules which govern traversal of the matrix and suggestions of alternative design configurations have been validated by user response. While the matrix is better at suggesting similar configurations than not similar, even the suggestion of not similar configurations offers better congruence with user responses than if the matrix suggested alternatives randomly.

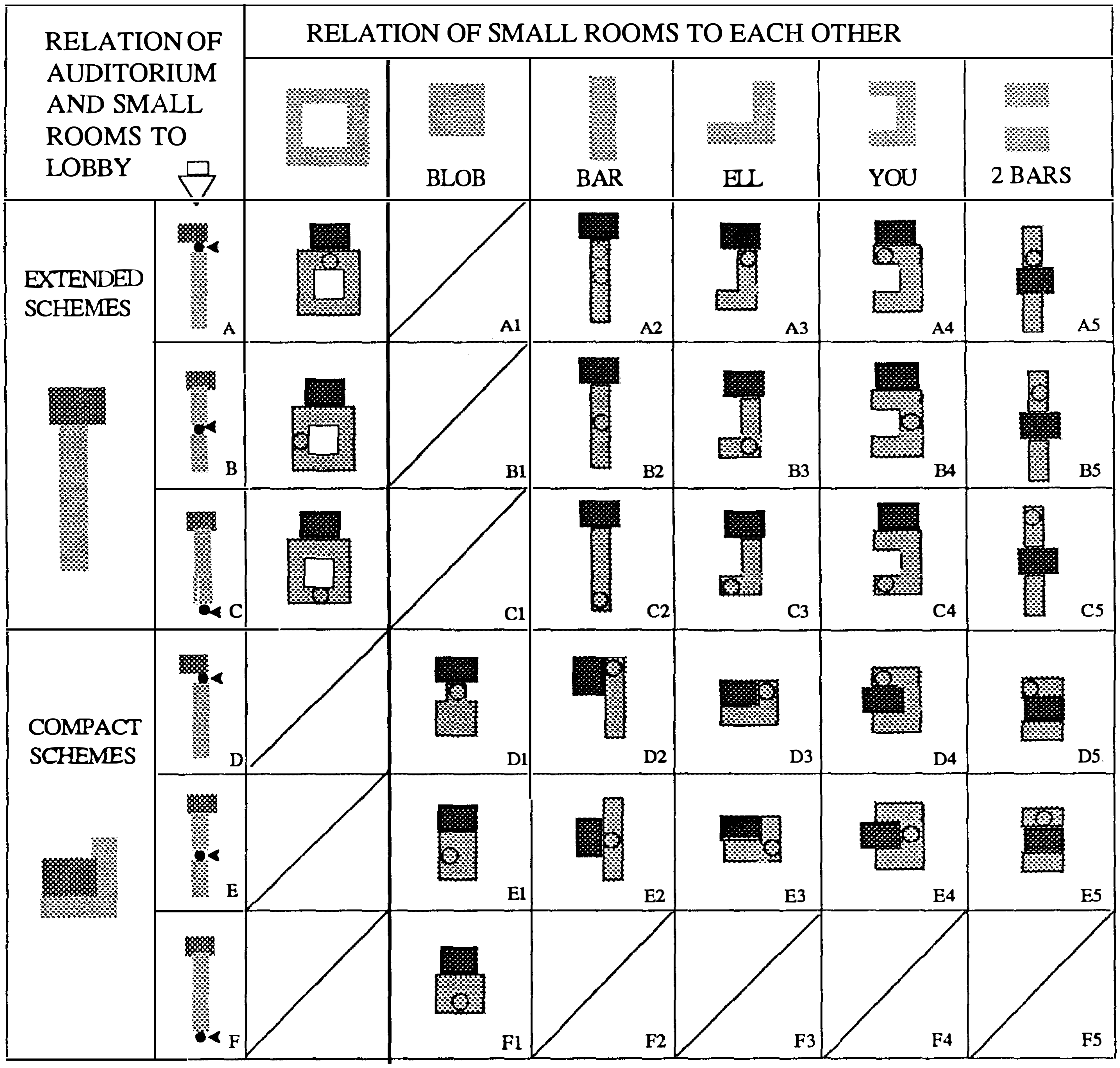

Figure 5.3 - 2
Matrix as revised to accommodate courtyards

6.0 CONCLUSIONS

Phase One Evaluations

- The matrix correctly predicted users' choices in the percentage shown in illustration 6.0 - 1.
- The order of the small room columns needed reorganization.
- The way the lobby was graphically represented in the compact schemes was unclear.
- The subjects' selections may have been based more on the geometric attributes of the scheme than would have been the case if the subjects had designed the building before making similar and dissimilar choices.

Avg. # correct	**Most Similar**	Next MostSim	NextNext MostSim	NextNext LeastSim	Next LeastSim	**Least Similar**
1st phase	37.4%	42.4%	56.6%	7.4%	10.6%	12.8%
Ref. Freq.	4.5%	4.8%	5.0%	5.3%	5.6%	5.9%

(Reference frequency refers to that probability of suggesting the same configuration by random chance, assuming that the most similar configuration has a 1/22 chance of being chosen, and the least similar configuration has a 1/17 chance of being chosen.)

Figure 6.0 - 1
1st Phase–Most and Least Similar Responses

Phase Two Evaluations

- As a result of this evaluation the arrangement of the small room columns was modified from a blob, bar, two bars, ell, U to a blob, bar, ell, U, two bars arrangement.

Phase Three Evaluations

- The revised matrix correctly predicted users' choices as shown in illustration 6.0 - 2

Avg. # correct	**Most Similar**	Next MostSim	NextNext MostSim	NextNext LeastSim	Next LeastSim	**Least Similar**
3rd phase	48.0%	62.3%	72.2%	8.2%	17.8%	31.2%
Ref. Freq.	4.5%	4.8%	5.0%	5.3%	5.6%	5.9%

(Reference frequency refers to that probability of suggesting the same configuration by random chance, assuming that the most similar configuration has a 1/22 chance of being chosen, and the least similar configuration has a 1/17 chance of being chosen.)

Figure 6.0 - 2
3rd Phase–Most and Least Similar Responses

- The increased percentage of correct answers demonstrated that the matrix could be calibrated to a user group to increase its predictive power.
- Doing the design problem first changed the users' perceptions of what schemes were similar and least similar.
- Most of the designs clustered around compact schemes and blob small room arrangements, confirming our hypothesis that strong and weak poles exist on both axes.
- A courtyard arrangement should be added to the small room axis.
- The matrix is better at predicting similar arrangements than dissimilar arrangements.

We feel that the matrix can be further refined to increase its predictive power. The matrix format can apply to the entire range of architectural issues, not just energy. In addition, our experience using this method suggests that it will be possible to link together matrices in a range of scales from site to component.

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The Advanced Energy Design and Operation Technologies (AEDOT) Research Project was created to develop a scientific and technical basis for improved energy-related decision making early in the design process and in ways that impact operational efficiencies. AEDOT research will develop intelligent computer-based tools to provide the technological basis for presenting and testing energy options.

The AEDOT 1 Prototype is a computer-based system which demonstrates the integration of advanced energy tools with computer-aided design (CAD) software. The prototype is intended to demonstrate some of the capabilities envisioned for the future that will help architects and engineers improve the energy efficiency of buildings during the design process. The development of AEDOT 1 is a collaborative effort involving the Pacific Northwest Laboratory (PNL), the California Polytechnic State University (Cal Poly), the Lawrence Berkeley Laboratory (LBL) and the University of Oregon (UO). (Quadrel, 1991).

8.0 REFERENCES

Brown, G.Z., et al. *Deadwood Community center and Firehall, Deadwood, Oregon*, Eugene, OR: Equinox Design, 1980.

Quadrel, Richard *Description of the AEDOT 1 Prototype.* Pacific Northwest Labs, Richland, WA., December 1991.