

Predicting Architects' Plan Preferences

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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 building plans and select building components and materials. This paper addresses the plan 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.

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 in-process CAD drawing, identify its plan and suggest another plan that the designer would like but that would have the potential for better energy performance.

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 3. Because each cell is generated from the axes of the matrix, the rows and columns that intersect to form any particular cell are asked to repeat test one, finding similar and dissimilar plans for each cell.

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. 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 1.

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 design. For example, if C (fig. 1) 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

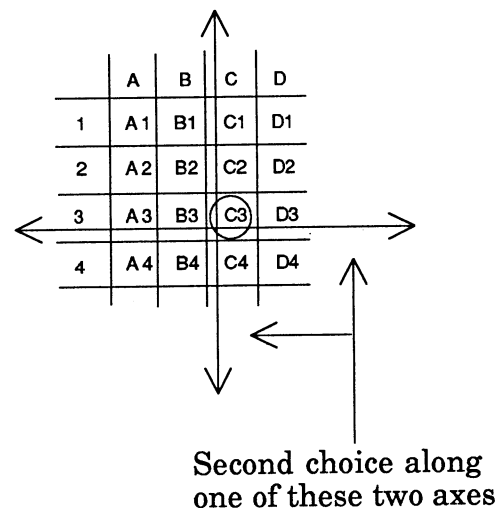


Figure 1, Subsequent Choices Within a Matrix

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.

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 enfront roads or open spaces.

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.

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 commu-

nity 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 WC's 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.

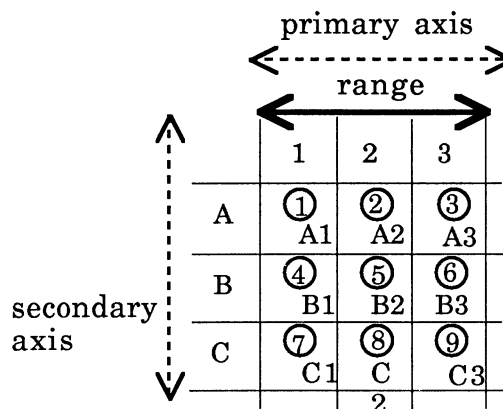
Ranking Matrix Cells

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.

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. There are of course many subtle variations between each step.

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 the designer were to draw cell C3 first, we could then



⑨ - numbers in circles represent energy rank

Figure 2, Cell Selection by Energy Rank

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.

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.

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 designer preference.

Using the techniques described in this section we developed the plan matrix shown in Figure 3. 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.

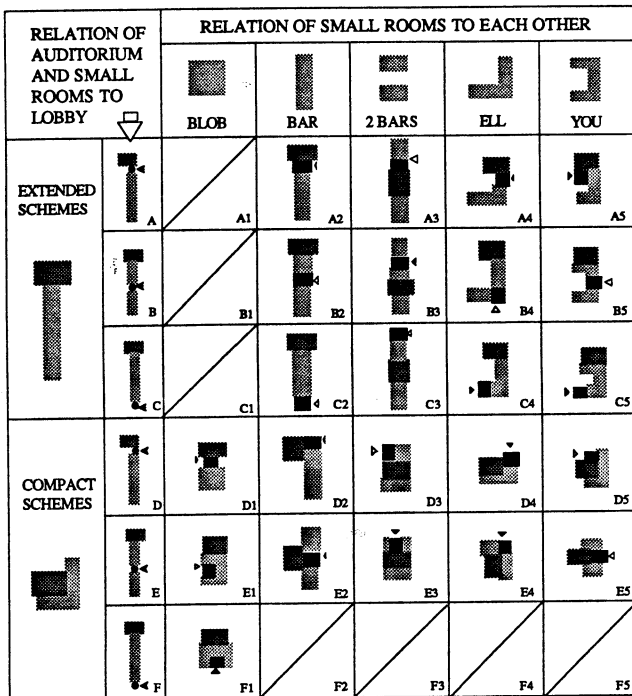


Figure 3, Plan Morphologies for a Rural Community Center

Traversing the Matrix

Once the Morphological Matrix is set up (fig. 3), 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 hypothesized that the more compact schemes are the strong pole, so the cell F1 would contain the strongest design (see Figure 4). 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.

A 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). Note that some cells are skipped because they are empty.

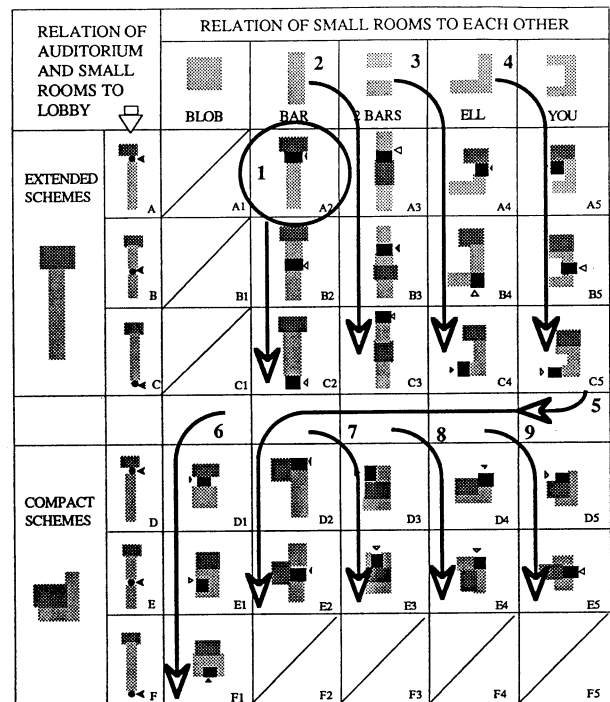


Figure 4, Traversing the Morphological Matrix Utilizing the Strong Pole of the Axes

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.

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. 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.

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 problem 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.

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)

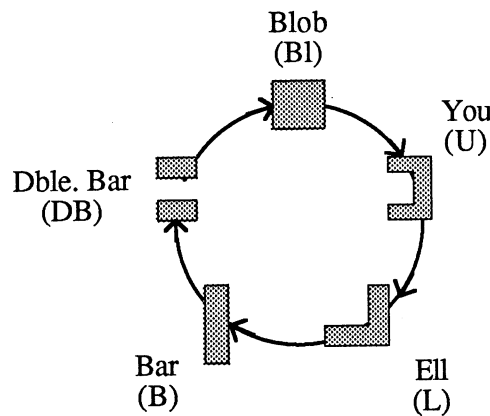


Figure 5, Sequential Arrangements of Small Rooms

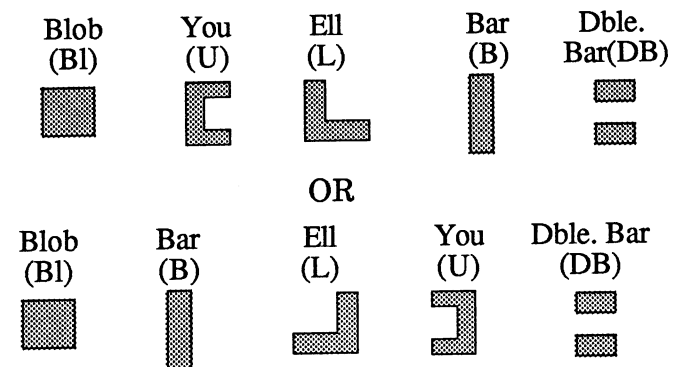


Figure 6, Small Room (Columnar) Progressions Favored by Users

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 diagrammed 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.

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.

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 7.

Third Phase: Design Problem and Configurations Relationships

In the third phase of the evaluative process, 18 subjects 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.

RELATION OF AUDITORIUM AND SMALL ROOMS TO LOBBY	RELATION OF SMALL ROOMS TO EACH OTHER					
	BLOB	BAR	ELL	YOU	2 BARS	
EXTENDED SCHEMES	A	A1	A2	A3	A4	A5
	B	B1	B2	B3	B4	B5
	C	C1	C2	C3	C4	C5
COMPACT SCHEMES	D	D1	D2	D3	D4	D5
	E	E1	E2	E3	E4	E5
	F	F1	F2	F3	F4	F5

Figure 7, Matrix as Revised at the End of the Second Phase

CONCLUSIONS

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.

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

Total	Most Similar	Next MostSim	NextNext MostSim
correct resp.	131/273	170/273	197/273
Avg. # correct	48.0%	62.3%	72.2%
Ref. Freq.	4.5%	4.8%	5.0%
Total	NextNext LeastSim	Next LeastSim	Least
correct resp.	22/269	48/269	84/269
Avg. # correct	8.2%	17.8%	31.2%
Ref. Freq.	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 8, Summary of Most Similar Responses

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.

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.

ACKNOWLEDGMENTS

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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 was 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).

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