USING CAD IN FIRE SAFETY RESEARCH

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ABSTRACT

While architecture offices are increasingly using CAD systems for drafting purposes, architectural schools are pursuing projects that use the CAD data base for new applications in the analysis and evaluation of buildings. This paper summarizes two studies done at the University of Michigan, Architecture Research Laboratory, where the CAD system was used to develop a fire safety code evaluation program, and an emergency egress behavior simulation.

The former one takes the National Fire Protection Association (NFPA) Life Safety Code 101 [5] as a basis, and generates the code compliance requirements of a given project. The other study accepts people as information processing beings and simulates their way finding behavior under emergency conditions. Both of these studies utilize the graphic characteristics of the CAD system, producing color displays on the CRT screen, and also outputting information in tabular form which refers to the display on the screen. Both of them also have plotting options.

INTRODUCTION

Traditionally, the results of research done in the area of fire safety have been conveyed to other disciplines by the use of codes. Lack of coordination with the fire protection engineer at the earlier stages of the design process has in the past led to minimum compliance with the codes, creating environments with a limited degree of fire safety. The need to cooperate at the earlier stages of design is now beginning to be recognized, since by doing so, one can easily reduce the number of modifications necessary at the later stages and can create safer environments.

Considering the number of fire safety concepts interacting with each other, computers were seen as a comprehensive and flexible tool in performing the initial code compliance check of a given project. A fire safety code compliance checking program was developed at the University of Michigan, Architecture Research Lab. by using the data base provided by ARCHI:Sketch [11], which is a CAD system developed in the laboratory under partial funding from US. Army Corps of Engineers. Besides the graphics advantages offered by the computer aided design and drafting system, it was also possible to do many of the routine calculations required by fire and life safety codes at a much faster rate.
The second study focuses on the understanding and prediction of the way-finding behavior of people in fires. Detailed investigations of a number of fire incidences have suggested that occupant safety is not solely a technological problem [2]. As a consequence, there have been several efforts to model and analyze human behavior in fires. While such models have yielded significant insights, the majority of models remain purely conceptual in nature and with limited predictive power.

Those models which have been operationalized as working computer simulations usually focus upon physical rather than behavioral variables [3]. But here again, the substantial literature in the field of environmental perception and cognition is yet to be incorporated into models of egress behavior in fires [8]. Therefore, a computer simulation was developed at the Un. of Michigan, School of Architecture, to integrate environmental cognitive factors into the decision process of route selection during emergency exiting and to use a more comprehensive model in the simulation, so that a framework to test different conceptual models can be created.

**FIRE SAFETY CODE EVALUATION PROGRAM**

ARCHIFIRESAFETY [9] is an interactive program to execute code evaluation at the early design phase of a project. The program is highly graphical and a Tektronix 4014 is the terminal that will support its features. The data base stored by running ARCHISketch is accessed by ARCHIFIRESAFETY. Since egress design is a very important factor in the early design phase of a project, the NFPA Life Safety Code [10] [11] was chosen as a basis for the program. The approach taken in the program was to identify essential processes from the code, to apply them to a specific building, and to generate a plan specific evaluation report.

**STRUCTURE OF THE PROGRAM**

The program is structured according to the flowchart shown in Fig.1. It is conceptualized in five different sections, not all of them controllable by the program user. Those that can be selected by the user are provided in a MENU, while others are executed automatically.

**Enter Code Requirements**

This is an automatic process, where codal requirements are read in from a permanent file. These requirements are stored according to the type of occupancy of the building. There are twelve occupancy types recognized by the program, which were determined by using the classification provided in the Life Safety Code. Some of these occupancy types are: assembly, health-
care, residential, mercantile, business, industrial, and storage. There are also thirty-three parameters stored in the code requirement file. Some of these are summarized in Fig. 1. Additional parameters are provided in those cases where total sprinkling of the building influences a particular parameter.

There are two other files that provide the necessary data base for evaluation. One of these store acceptable activity names for which the program can generate occupancy loads, in those cases where activity type influences the allowable number of people in a space. The other file stores the fire ratings of materials and is accessed whenever wall ratings are checked. These materials are also recognized by the energy analysis section of the main program, providing compatibility between different evaluation programs.

![Fig. 1 Conceptual structure of the program](image-url)
Building Description

The general plan configuration of the building is provided by ARCHiSketch\textsuperscript{[11]}. Not only the geometry of the building, but also the activity names, and the names of the materials for walls, ceilings and finishes can be accessed.

The next phase is to define the fire safety features of the building, which is done through the MENU by choosing different options (Fig. 2). Horizontal exits, i.e., fire zones; smoke barriers; egress routes; hazardous areas and additional occupancy areas, i.e., those spaces that are defined to be a different occupancy type than the general occupancy of the building can be given by using the MENU. Since the information about the building project is stored in 2-dimensional graphics form, any element on the screen can be identified by pointing to it with the crosshairs and by finding it in the data base. This method is used in entering the fire safety features of the building.

The only processes that are not in the MENU are entering the occupancy type and entering the acceptable activity names. Since without this information the program cannot provide any evaluations, these processes were made compulsory. The activity names are used both to calculate the number of people in the building (the occupancy load) and to identify hazardous areas and exit ways.

Fig. 2 The MENU and the inputting of fire safety features
Internal Consistency Check

These are the processes that are automatically executed whenever a new fire safety feature is described to the program. They are closely related to the definitions used within the program. Continuity of fire zones; continuity of smoke barriers; integrity of egress routes, i.e. if they properly discharge through an acceptable exit, such as an exterior door; the existence of acceptable exits are some of the consistency checks. Wall ratings are also cross checked whenever a fire safety feature is changed or deleted, since a particular wall may need to be fire-rated due to several different fire safety features in a building.

General Requirement Report

This report provides information about codeal requirements of a particular occupancy type. The only information needed for this is the type of occupancy of the building. The report is not plan specific, but provides additional information that is not covered by the plan specific evaluation.

PLAN SPECIFIC EVALUATION

This is where the evaluation of a particular building is done using the code requirements entered previously. The fire safety features defined by the program user provides the necessary basis for this process. The MENU enables the user to go into different evaluation modes, as well as going into different fire safety definition modes. Thus the user can change fire safety features of the building instantly and retest them, when code violation is encountered during plan specific evaluation.

The number of people allowed in a building influences the nature and the physical dimensions its fire safety features. Therefore, before any calculations can be done, allowable number of people at any currently evaluated floor is found. The program recognizes the occupancy type and calculates occupancy load either in net area or in gross area mode depending on the requirement of the code. Gross area mode considers total floor area including walls, whereas net area mode excludes all wall area plus the areas of spaces such as rest rooms, corridors, stairs etc.

Horizontal exit evaluation

There are three basic code checks in this area:
1. Area check. Total area of each zone is calculated and a warning is issued if the area is larger than the codeal limit. If
the occupancy type of the building does not impose a limit on the fire zone area, the user is informed with a message.

2. Wall ratings. The walls that surround the fire zones are rated and their required ratings stored, while simultaneously displayed on the screen.

3. Number and capacity of horizontal exits. Here, the requirement which limits the capacity of the horizontal exits to a maximum of 50% of the total is checked. First the capacities of all existing exits are calculated, then the required width is found by using the number of people at current floor. A warning message is issued if the capacities of exits are not enough. The capacity of horizontal exits is calculated separately and compared to the required ratio from the code.

Smoke barrier evaluation

1. Smoke distance check. Finds the distance between smoke barriers and/or exterior walls, and warns the user in case of non-compliance.

2. Smoke area. Checks to see if there is a need for more than one smoke area due to the number of people at current floor. A smoke area is defined to be the total area of all spaces that are bounded by smoke walls and/or by exterior walls.

Egress evaluation

There are three types of evaluations performed:

1. Minimum corridor width check. If the width of an exit access corridor is less than the codal requirement, a warning is issued.

2. Stair width calculations. All protected staircases are found, and their capacities and minimum widths are checked. In calculating acceptable exit capacity, an exit unit of 22in. is taken as a basis as required by the code.

3. Capacities of doors. All doors leading to egress routes are found, and their capacities checked.

Travel distance calculations

This mode finds all protected exits and exterior doors, and finds the distance to these exits at current floor. Protected exits are defined to be all those leading to a protected egress route or to an adjacent fire zone. The travel distance is found from the furthest point in each room (Fig.3).

Wall rating report

The purpose of this mode is to compare the required ratings of the walls with the fire ratings of the materials, and to warn the user if the material does not meet the requirements.
This study mainly focused on some of the concepts covered in the Life Safety Code. It is possible to extend this approach to other areas such as fire safe detailing and construction. The advantages of using computers for code compliance checking are that the flexibility offered at the design phase before the actual implementation of the project is done; the educational value, since interactions can be seen more clearly during planning; and the possibility of saving lives, since during an emergency one can easily locate the hazardous materials and see how the building circulation is designed. As from the viewpoint of the architect, the most important step will be when a library of architectural details and their fire ratings are provided in the computer and can readily be accessed by the architect.

Fig. 3 Travel distance calculations
BGRAPH: A COMPUTER SIMULATION OF THE BEHAVIOR OF PEOPLE IN FIRES

Three important areas of research are reflected in this study: fire safety, environmental psychology and computer aided design.

A variety of conceptual models are found in fire safety literature, often reflecting clear differences between disciplinary perspectives. To name a few of these, Withey[14], Bryan[11], and Lerup[6] have all proposed different conceptual models. One common element they all seemed to agree was the existence of behavioral episodes or action sequences. This episodial nature of the conceptual models of human behavior in fires was taken as a basis in developing the computer simulation.

Way finding behavior is obviously central to any discussion of emergency egress behavior. The conceptual models developed in other fields have not really addressed the issue of way-finding and route selection in fires, somewhat disregarding the impact of the physical environment on the human behavior in fires. One of the most traditional environmental variables recognized by fire professionals was the exit signage, although recent studies of actual fire incidences[1] reveal that only 7-8% of people use signage during fire emergencies. Other studies under non-emergency conditions have brought several other environmental factors to the attention of the researchers. Factors such as perceptual access, architectural differentiation and plan configuration were found to be effective in the way-finding behavior of people[12],[8]. Therefore, a building by the virtue of its design was effecting the spatial behavior of its occupants. Now there was a need to incorporate environmental factors into a model of emergency egress behavior.

The majority of the computer modeling efforts in fire safety have been directed toward the behavior of fire and smoke[7], rather than the behavior of people. The only implemented model that meets such a definition is Stahl's BFIRES II[10]. This model provides a sound basis and sets a good example of how behavioral simulation can help to clarify conceptual issues to greater detail. BFIRES II, and to our knowledge, no other computer model of emergency egress behavior have really explored the possibility of using a CAD data base for building description. In the past, this has led to some simplifications of the building system in terms of nodes, grid systems etc.[3]. The sketching and drafting program at the Un. of Michigan, Architecture Research Lab. provided the opportunity to use the CAD data base for behavioral simulation.
The conceptual frame of the model, BGRAF, is based on the episodic nature of the human behavior in fires, where each episode can be identified by a particular goal, be it exiting, rescue or fire fighting. A change in the current goal signifies the end of a particular episode and the start of a new one. The decision process simulated in the model is the choosing of the next goal, which in turn triggers a set of new actions. An action library provides the list of actions that can be taken by the people simulated in the model, such as stay in place; go to door; go to exit; go to fire area; go to alarm; turn back etc. By using these actions like building blocks and relating them to whatever goal is currently implemented, the user can experiment with different goal structures and action sequences. The assignment of a set of actions to a particular goal is done by the model user, depending on the nature of the occupancy simulated and the characteristics of the people in the simulation. For example, if the occupancy type of the building represented in the model is health care, simulated people could be patients, staff or visitors. Each of these groups will have different characteristics and thus will take different actions and choose different goals at any point in time in the model. Where a nurse may be more likely to fight the fire, a patient might be more likely to wait for rescue or try to evacuate. This process is reflected to the model in terms of the probabilities assigned to different goals. Thus the simulation is a stochastic one, where information from actual fire incidences determine the values assigned to these chance parameters.

Representing the Fire Event

Fire descriptors are mainly related to the location of the fire in the building and the spread rate of the smoke. The connection to CAD lies in terms of the horizontal spread of smoke in the building. Once the origin of the fire is inputted interactively by the model user, the smoke spread rate is asked. All data is stored in terms of Cartesian coordinates and thus the smoke spread is represented on the 2-dimensional surface at any given floor, while the modeling of fire spread to other floors represent the vertical spread. When fire spreads to other locations at current floor or spreads to other floors, a multi point spread process is introduced. Although this model is quite sufficient to simulate documented fire incidences, it was intentionally designed as a support for the human behavior part of the simulation, rather than as a fire spread model which aims at making predictions about potential fire spread in a given building. National Bureau of Standards, Center for Fire Research has within the last decade developed several fire spread models with predictive power [4]. Currently there are plans to use FAST fire spread model developed at NBS, Center for Fire Research in connection with the behavioral simulation and the graphic capabilities of BGRAF.
Route Modifier Library

The influence of environmental factors, such as perceptual access, architectural differentiation and plan configuration are reflected to the model through the route modifier library. By increasing the preference levels of those spaces with architectural differentiation and perceptual access, each room is assigned with a weight which in turn determines its likelihood of being chosen during an action in any given time frame in the model. The familiarity of the occupant with the building is also incorporated into BGRAF by considering the distribution of activities in the building. The CAD system provides the activity names for different spaces in the building. By identifying those common ones such as corridor, cafeteria, lounge etc., spaces with key activities are assigned with higher preference levels, where these spaces are more likely to be chosen by the simulated people in the model. The model user is also free to designate additional key activities, which allows one to simulate different occupancy types.

Model Description

BGRAF is a stochastic model, where the probability of occurrence of different goals and the related actions, provides the basis for the simulated decision process. Passing of time is simulated in terms of time frames. At any given time frame, every simulated occupant is processed and the goal they would pursue in that time frame is selected. This goal could be same as the one in the previous time frame or a new one, depending on the environmental factors and the completion of the action related to current goal. Fire spread is also simulated in terms of time frames. First the fire spread at current frame is processed and displayed on the screen, and then the decision process for each occupant is implemented and if a decision to move is reached by any particular occupant, his new location in the building is calculated. Then he is moved on the screen, where the plan of the current floor is displayed continuously.

The frequency of the simulation, i.e. the duration of each time frame in minutes, is calculated internally by using the total length of the event in minutes and the total number of time frames given by the user. This enables the model user to simulate any given event by using different number of time frames. Since the simulated egress decision is processed at every time frame, the frequency of the simulation is an important parameter and its potential effect on the total process is currently explored.

The speed of movement of an occupant depends on his physical status. Therefore the model user is asked to enter two different values, one for the regular and the other for the handicapped walking speed.
The statistics gathered in the model is mostly related to the action sequence displayed by each occupant; the time the occupant has reached safety, if ever; the distance travelled by the occupant; the length of stay in smoke infiltrated areas etc. This information is saved in a permanent file, from where it can be retrieved later by the model user (Fig. 4).

**Model Validation**

Data from existing post facto investigations are used for model validation. The ability of the model to produce action sequences similar to those reported by different researchers is the measure of model validity. Several runs are currently done with the data derived from an NFPA report on a fire incident at WestChase Hilton Hotel [13]. The probabilities assigned to different goals prove themselves to be very important in producing results similar to the actual fire incident. Data from Project People II, which is a study of more than 90 fire incidences by Bryan[11] is used as a basis in assigning probabilities to goals.

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Fig. 4 An output of the behavioral simulation in tabular form.
One important problem often encountered by researchers in the validation of models is the lack of data on the specific details of the simulation. Especially environmental cognitive factors, having only recently been applied to the field of emergency egress, greatly requires additional field tests and studies. Since fire reporting practices are only beginning to include information on human behavior, very limited information was found on the egress related attributes of the physical environment. Therefore, this is an area that needs further research and data generation.

SUMMARY

The CAD data base was found to be an important factor in generating new applications, and in exploring new ideas. Having a sound description of the building in the computer eliminated the need to simplify the building in terms of nodes or grids, and enabled the researcher to do much more accurate calculations and generate a reliable assessment of the building project under study. This was a major contribution of the CAD system to the code compliance checking program.

The ability to move the simulated persons to any desired location in the building, to be able to see the movement of people and the spread of fire instantly on the screen, and to be able to enter information about the fire event and the people location directly through the screen by using the crosshairs were the most important advantages of using a CAD system for behavioral simulation. It did require additional graphic algorithm solving, which was an important challenge in the development of the model. Especially the travel routine, which solves the movement of the occupant in any given room, no matter what shape it is, and towards any other desired room, no matter how remote it is, required considerable algorithm development.

A new area of computer applications, which is sometimes called intelligent computing or expert systems, is emerging in the field of architecture as well as in many other fields. The CAD systems are changing, they are not merely drafting tools any more, they are on the way to become a tool in the assessment of buildings, a communication medium through which building professionals from different disciplines can communicate, and can generate interacting ideas and concepts. Therefore, the need to develop new ideas, new applications is recognized by different architectural schools around the country, and as a result different applications are being developed and implemented.
REFERENCES


