SIMULATION OF THE EMERGENCY EVACUATION OF BUILDINGS IN THE EVENT OF FIRE

Application of the Computer Program AIR-Q by final Year Architecture Students.

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ABSTRACT:

The paper describes an application of CAAD techniques by Final Year architecture students using the computer program AIR-Q to dynamically simulate the emergency evacuation of people from a multi-storey department store. This is presented in the context of a fire emergency and reference made to the local Building Regulations which govern the size and location of fire exits. It is suggested that the technique not only provides students and designers with an easily assimilated understanding of the consequences of design decisions but also allows alternative design solutions to be quickly compared in a search for the, optional design strategy. The exercise also demonstrates, to the students, the logic behind the rules contained in the Fire Regulations while demonstrating possible weaknesses and inadequacies of the empirical approach that these regulations are constrained to adopt.

CAAD EDUCATION IN THE SCHOOL OF ARCHITECTURE

Architecture students in all years of the school have varying levels of contact with the computer. Initially this involves using CAAD for simple heat-loss, U-value and Daylighting appraisal in the early years through to more complex applications in later years with programs such as GOAL (1), BIBLE (2) and E.S.P. (3). Always the emphasis is on using the computer as a design tool so that much of the early studies are combined with the philosophy of 'Design Methodology'. A major project (using GOAL) is carried out in the 3rd Year of the course and thereafter use of CAAD techniques is entirely optional, depending on the self-motivation of the students. This paper describes one such optional use made by students in the final (6th year) of the course using the computer program 'AIR-Q' (4).

THE CAAD/AIR-Q PROJECT

Final year (post-graduate) students are required to design a major building from initial sketch through to detailed production drawings. The choice of building type and development of the design brief is each student's own responsibility and, within this selection procedure, the student also chooses a specialist topic for detailed study. One such available specialist topic is the use of CAAD during the design process (or as an aid related to a particular aspect of the design problem).

During the 1982-83 session, two students expressed an interest in applying simulation techniques to determine the effects of play layout on the flow of people within the building, and in particular, using the simulation program AIR-Q to simulate the emergency evacuation of the building in the event of fire.

The chosen design problem was for an urban infil development involving design of a new multi-storey department store. Having first determined a general design solution - a total of 6 floors including a basement - the objective was then to test the evacuation time for the building (assuming possible variations

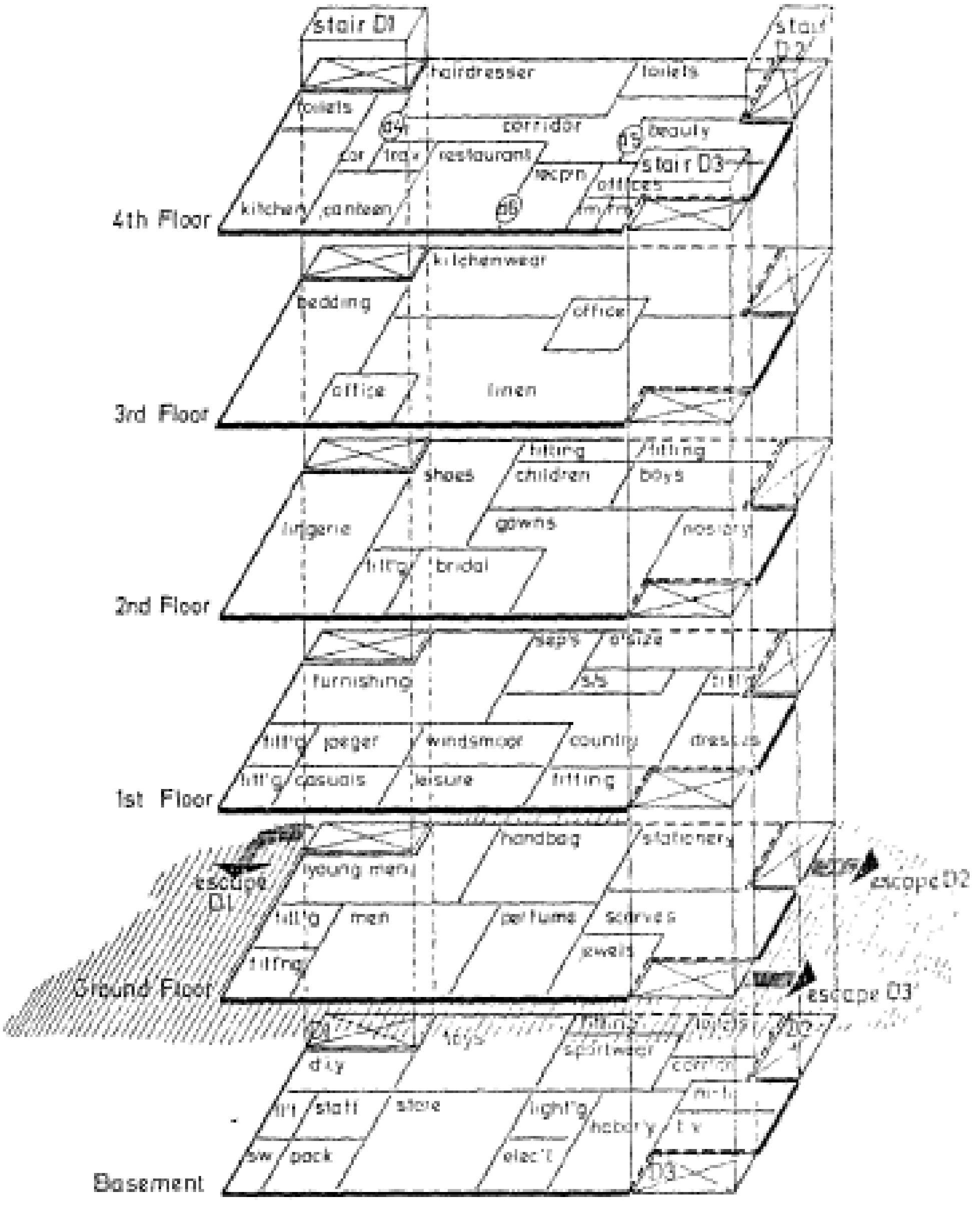

FIGURE 1
DEPARTMENT STORE
General Layout of Accommodation

in exit routes for each floor) and to compare this with the statutory standards set out in the Building Regulations (5).

Figure 1 illustrates the general disposition of plan elements in the design and the location of vertical exit routes (stairways). It should be noted that, in Scotland, only stairways may be used in the event of fire and so other alternatives (eg lifts, escalators) are excluded from consideration within the simulation model.

THE AIR-Q PROGRAM

The AIR-Q program was originally developed (by the author) as an aid for airport designers or for any building type which involved the flow of large numbers of people or goods. The technique is based on a combination of Markov Chain theory and dynamic timebased stochastic modelling of flow rates and service times. The program has been adequately described elsewhere (4,6,7) but its potential for simulating building evacuation had only been explored twice previously (7,8) and these sources were made available. to students at the commencement of the project.

Within the context of the AIR-Q program, the following explanation is given of the operation and modelling of the various design variables.

"Exogenous Variables"

1. Activities Net-work

    Each plan element in the layout is identified as a discrete activity eg Menswear Department, Hairdressing Salon, Restaurant etc, and, included as activities, doors and corridors associated with evacuation routes.

    Activities are linked according to the directions in which flow will take place and, when options occur for direction of flow, a percentage value is assigned to each link according to its proportionate usage.

2. Population Distribution

At the start of the simulation, each activity node in the network is assigned an expected starting population. For the purpose of simulating emergency evacuation, the starting population are calculated by the user as being the maximum number of people one might expect during a particularly busy period.

3. Average Stay Times

Each node in the network is assigned an "Average Stay Time". In the usual AIR-Q context this represents the average tine a person will require to complete an activity. For the purpose of this exercise, "Average Stay Time" is taken to man the average time an occupant will require to recognise an alarm and move to the exit point from each activity. This involves a combination of estimation of response times and travel time across the activity space.

4. Bottleneck Activities

Certain activities in the network give rise to restrictions to flow - for example doorways and narrow corridors. These require more sophisticated modelling and are, for the simulation, identified as "Queuing Nodes".

Queueing Nodes

Progress through queueing nodes within an AIR-Q network is controlled by reference to stochastically generated service times (based on a Negative Exponential probability distribution) and number of servers available. Where doors are to be modelled as queueing nodes, the control parameters are calculated ass follows.

The Scottish Building Regulations (5) contain criteria which implicitly suggest that a door width of 530 mm will allow the passage of 1 person per each 0.025 minute. From this it is deduced that the 'Service Time' for a door is assumed to be 0.013 minutes per 1.0 metre width of doorway.

Within the students design, doors were taken as units of 0.9 metre width (ie double doors were 1.8 m wide and so on). Hence service times were calculated based on a 0.9 exit width and number of servers related to whether doors were single or double width (1 or 2 servers).

A fuller explanation of this logic is to be found in the authors thesis (7).

'"Endogenous Variables"

In simulating the evacuation of people from the building, the following endogenous variables where to be observed.

1. Queueing
   The incidence and build-up of queues at bottleneck activities (doors).

2. Queueing Time
   The length of time any observed queues took to disappear.

3. Total Evacuation Time
   The total time taken for all occupants to reach a "place of safety".

SIMULATION STRATEGY

The Scottish Building Regulations require that each vertical escape route within a multi-storey building be designed as a 'place of safety' ie each stair is enclosed within a fire and smoke fire structure. Consequently, it is only necessary to simulate the performance of each floor in the building as a separate and discrete problem. Also, the fundamental hypothesis on which the regulations are based is that each floor (fire compartment) should be totally evacuated within a period not exceeding 2.5 minutes.

Therefore, separate activity networks were created for each floor and each was tested separately. Two networks are required for each simulation - the 'Open System Network' used for the simulation proper.

The Closed (Preload) Network

The application of Markov theory for preloading the closed network has been described elsewhere (4,6,7). However, for this application, the closed system Is in fact preloaded with a nil population (ie there is no-one in the system at the start of the simulation). Instead, actual preload is performed in the open network using a 'Trigger Input Node" to assign the pre-determined starting populations to the various activities.

The Open (Simulation) Network

Fig 2 illustrates a typical open system network used in the simulation. The example chosen relates to a Fourth Floor Plan (total expected population for simulation purposes was 161 people). For simplicity, the reminder of this paper will deal only with this particular network as an example but it should be borne in mind that all floors had to be similarly investigated and various design alternatives explored.

Simulation Period

Because it was to be expected that all activity nodes should be evacuated within 2.5 minutes, each simulation period was restricted to only 3 minutes with an incremental time step of 0.02 minutes (1.2 seconds) ie a total of 150 per simulation.

(Normal AIR-Q simulation use time intervals of about 4 hours with a time. step of 1.0 minutes which represents therefore 240 per simulation).

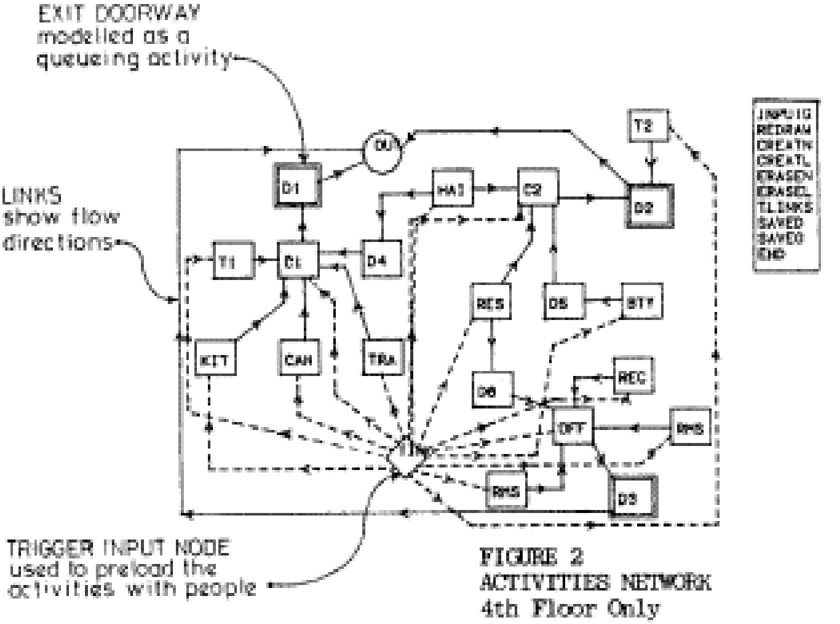

FIGURE 2
ACTIVITIES NETWORK
4th Floor Only

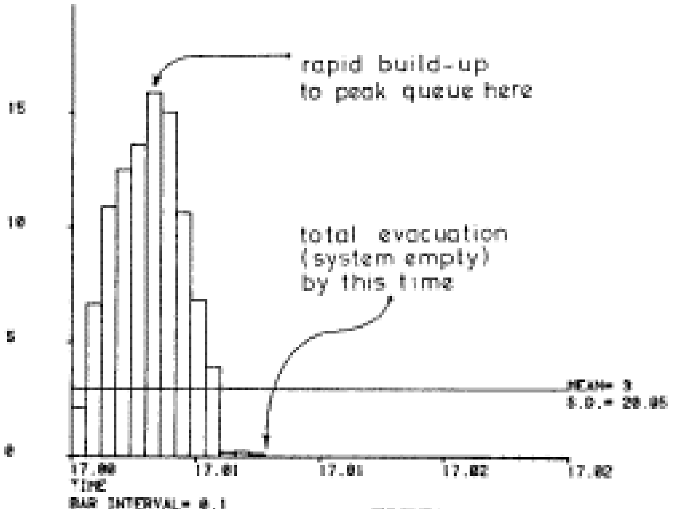

FIGURE 3
TOTAL EVACUATION
Combined D1, D2 and D3

RESULTS

Having run the simulation, the simplest way to check total evacuation time is to draw the combined population histogram for the three escape doors (corresponding to the three stair zones). This is illustrated in Fig 3 and clearly shows that, following an initial rush of population towards the doors, total evacuation had been effected in less than 1.0 minutes (approx 30 seconds). By drawing the individual histogram for each door in turn it was found that the largest crowds (queues) occurred at Door 2 where, within a period of about 7 seconds, a peak queue size of 15 people occurred. The implications behind this discovery am, left to the reader to deduce but it is obvious that the likelihood of panic causing vaulting (9) could or should not be ignored and it becomes worthwhile to explore alternative plan configurations to either produce a more even distribution over the three exit routes or to (paradoxically) impede the rate of arrivals at Door 2 so as to smooth-out the histrogram.

One other alternative strategy is worth describing, the determination of total number of exit stairs as set out in the Building Regulations is based on the possibility that one of these routes may in fact be unavailable (eg a smoke-filled stairway). To test the effects of such an occurrence is simple using, AIR-Q since all that is required is to delete the relevant node from the network and re-route the associated input link(s) to other exit routes.

Fig 4 shows a revised activity network similar to Fig 3 but with the node representing exit D3 removed.

The consequences of this are then shown in Figs 5 and 6 which demonstrate the effect on total evacuation time and the queue sizes at Door 2.

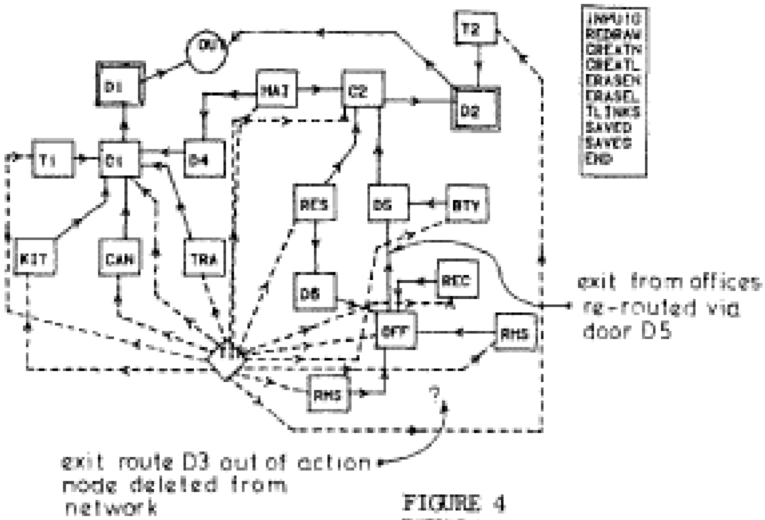

FIGURE 4
REVISED NETWORK
Exit D3 Removed

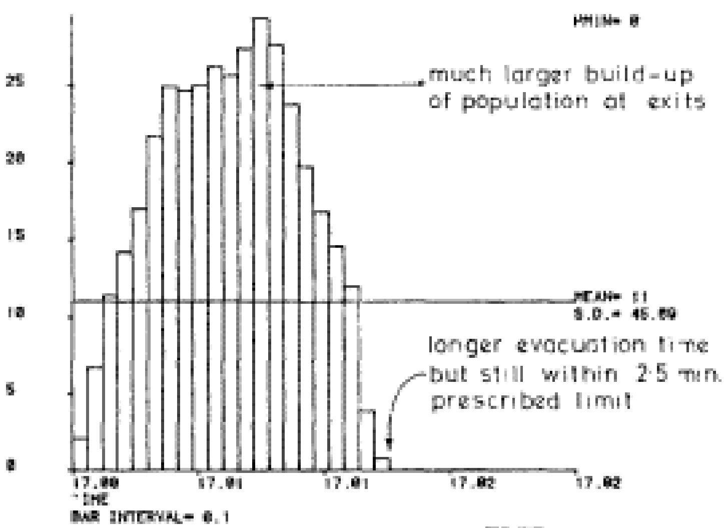

FIGURE 5
TOTAL EVACUATION
Combined D1 and D2

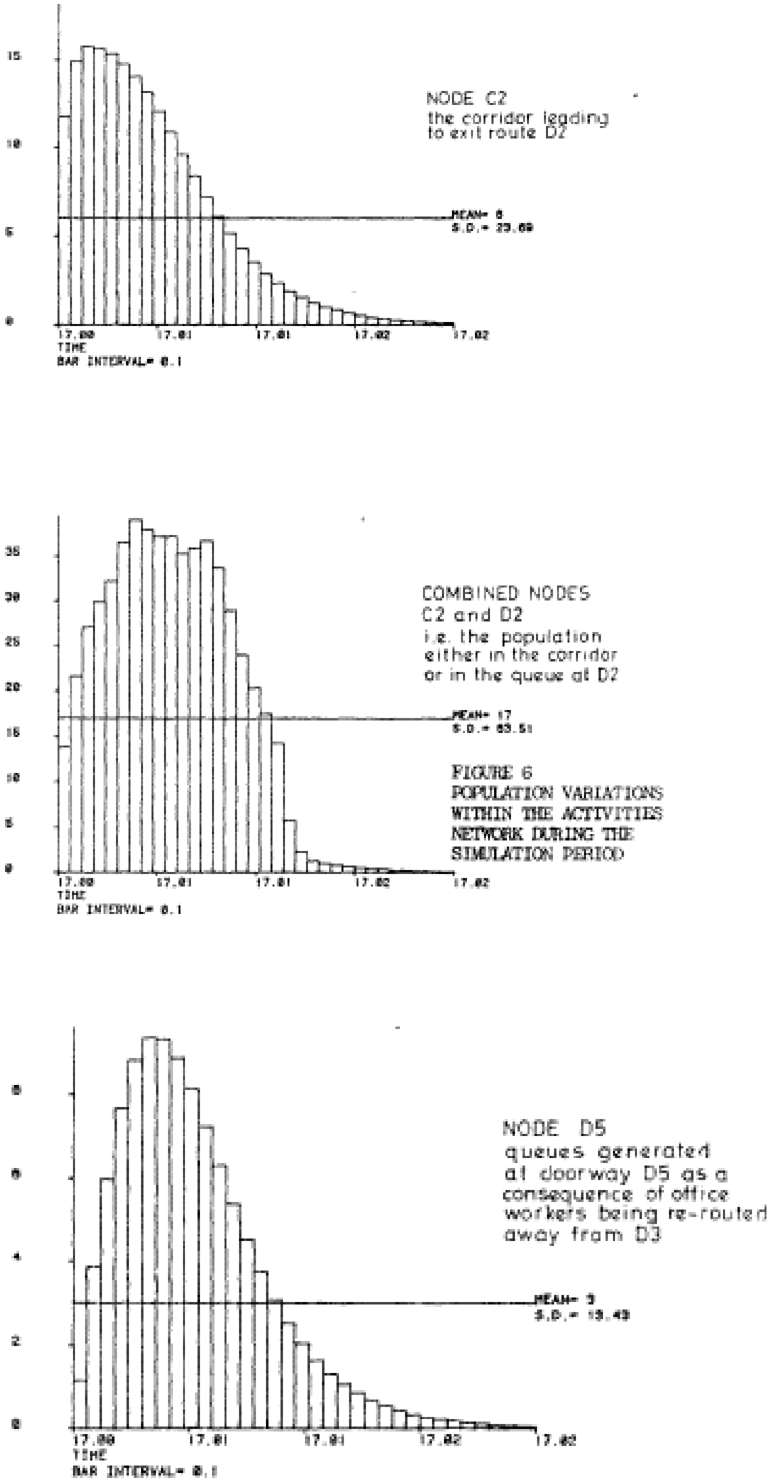

FIGURE 6
POPULATION VARIATIONS
WITHIN THE ACTIVITIES
NETWORK DURING THE
SIMULATION PERIOD

CONCLUSIONS

It is not the purpose of this paper to give a detailed report or analysis of the results of the exercise - this has been covered in the reports submitted by the students. Instead, the reader's attention is drawn to the potential offered by the technique as an educational device through which students (and designers) can be given a graphical understanding of the consequences of their design decisions. Furthermore, the ease by which solutions can be modified (while alternative design strategies are explored) demonstrates the power of CAAD as a design tool for rapid building appraisal using techniques which would be wholly unmanageable without the processing power of the computer. This latter point highlights the implication that CAAD does and should give rise to new (hopefully more efficient) ways of designing buildings and for which schools of architecture must inevitably provide the ideal test-bed.

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