Integrated Computer-Aided Architectural and Structural Design

A. A. Najafi
Department of Architecture and Building Science
University of Strathclyde
Glasgow G4 0NG, UK
E-mail: najafi@strath.ac.uk
Fax: 0044 141 5523997

1- Introduction

The decisions made at the early stages of design that generally take place in the architectural office have phenomenal effects on many aspects of building, including the structural form, the mechanical and electrical services, the construction planning, and the overall cost of the project. It is of prime importance that the effect of decisions which an architect makes in the initial stages of building design can be assessed; particularly vital is the influence of changes made in the spatial arrangement of building floors. The earlier in the design process these effects are studied, the better the later difficulties can be avoided.

A programme of research is in progress to provide a computer-aided learning tool for students of architecture so that they become familiar with the process of structural design, and examine the effects of the decisions they make at the initial stages of design on the structure of the building. It is also educative to observe how the architectural design of a building may be influenced by its structural arrangement. It is intended that the user acquire a general understanding of how steel structures behave.

The system proposed in this paper automates and integrates the activities at the conceptual and preliminary stages of architectural design of regular buildings, with the conceptual and preliminary stages of structural design, leading also to the detailed design of the building structure. The primary intention in designing the system architecture has been to follow the real procedure of building design as it happens in practice. As a result, the students of architecture can gain a better understanding of the structural design process.

The architectural practice carries out initially feasibility analysis, space needs analysis, interaction and grouping analysis, and spatial synthesis, followed by an initial (and very rough) cost estimate that complements the feasibility analysis. The schematic design of building then follows that involves sketching a number of alternatives, selecting the most suitable ones, and developing these suitable schemes. Once these schemes are developed in more detail, selection of the most promising scheme becomes possible. This scheme is then developed further, the outcome of which is the general arrangement drawings, issued for further work by other practitioners, e.g. architects, engineers and quantity surveyors. The outcome of each stage is presented to the client as appropriate, and the client's needs are taken into account as the design proceeds.

A soft copy of floor plans, normally in the form of computer diskettes, is often available to the structural engineer. The plans contain the layout of spaces, with a series of gridlines corresponding to the modularity of spaces in the architect's mind. These gridlines may not coincide with those drawn by the structural engineer, thus, a series of gridlines are created corresponding to the structural modularity in the structural engineer's mind. Once adjusted to the technical constraints, including the overall structural continuity, these gridlines are the basis for allocating structural elements.

The structural engineer considers a number of alternative solutions in line with the design brief and technical specifications of the project. The appropriate schemes are selected and developed further so that the most suitable one can be selected. This selected scheme is then developed in more detail, and provided that proper channels of communication exist, it is checked against the requirements of other practitioners.

For buildings of structural reinforced concrete and steel, the structural model is in fact a space frame, the engineer however views it as a number of planar frames the interactions of which are to be taken into account. In effect, the engineer decomposes the complex structure of the three-dimensional frame into a number of less complex two-dimensional frames composed of beams and columns.
The columns are located at the intersection points of gridlines, and the lines connecting these points in plan are taken as beams. The primary decision to be made is the selection of the type of planar frames in respect of their resistance to lateral loads such as wind and earthquake. Two main alternative structural systems are rigid frame and braced frame. Once this conceptual selection is made, the physical system is developed by designing beams, columns and connections.

The structural design method used in the proposed system eliminates the need for provision of bracing in the plane of steel frames. This feature is attractive in that the bracing does not exist to interfere with openings in the building, and therefore useful to be introduced to architectural students. The resistance to lateral loads, such as wind, is provided by the moment resisting beam-to-column connections.

Structural analysis of building frames requires sizes of structural components for calculating forces and displacements of members. If the resulting stresses and displacements exceed the allowable values, components' sizes should be altered and the frame reanalysed. Another feature of the design method is that it eliminates the need for initial sizing of structural elements. This feature is useful for architectural students as they do not need to make estimates of the sizes.

In order to make appropriate decisions on the implementation aspects of the system, a study was undertaken of computer use in education and practice. The following section will summarise the studies concerning the former.

2- Computer use in design education

The purpose of analysing the results of the surveys was to conclude the following issues in order to decide on the implementation mechanisms and platforms:

1) The hardware most widely used.

2) The suitable operating system.

3) The most appropriate software platform.

4) The suite of necessary application software.

5) The ancillary issues such as interface mechanism, data management, etc.

There seems to be less interest in surveying software and hardware in educational establishments than in the design practice. Essentially, the present state of computer use and its future trends have been of interest to this study. The works used by the author fall into the following categories:

a) Architectural education in the UK by Howes (1994) for the RIBA and in various countries by QaQish & Hanna (1997); and using the proceedings of ECAADE and ACADIA.


It may be fair to say that similar distribution of the type of hardware exists in universities across the UK, with far less difference in the percentage of PCs, Macs and workstations than is seen in the practice. Windows applications are widely used, and most recent papers describe educational software based on Windows using multimedia and virtual reality techniques.

The purpose of reviewing the related works was to identify the strengths and weaknesses of previous systems. The software developed at the schools of architecture essentially aim at providing a general understanding of structural concepts, therefore, the visual approach to teaching structures is the main feature of these systems. However, some of them have ignored the engineering precision and accuracy of the concepts and the exactness of fundamental definitions. On the other hand, some suffer from adopting unsuitable commercial programs with minimum input on the part of the educational body. The
overwhelming characteristic of all these systems is that they are discrete programs featuring a particular aspect of structural behaviour.

### 3- System implementation

The following decisions have been made in respect of the system implementation:

1) The hardware should be IBM Compatible microcomputer (Personal Computer). The PCs are by far the dominant machines in practice and education, and are in fact replacing the minicomputers in almost all applications. Present PCs are fast and powerful enough for many of the design tasks. The hardware used for the development of the proposed system was a 486 DX2 66MHz processor with 32 Mbytes of RAM connected to a Local Area Network.

2) The Windows environment should be Windows NT (the version used was 3.51). Windows NT is believed to be the future windowing system for many applications including AutoCAD. Windows NT has been described as being more reliable in terms of security and networking, and less vulnerable to crash.

3) The CAD application software should be AutoCAD as the most widely used CAD system. This software has now been developed to an overall solution system by continuously improving and extending its many features, including customisation facilities.

4) The generation of structural layout should be performed within AutoCAD using AutoLISP programming language. AutoLISP syntax is appropriate to manipulating drawing entities, list structures, geometrical relations, user interface, etc. It possesses features useful for reasoning and semantic representations, and can invoke all commands defined in AutoCAD.

5) The calculation intensive programs for structural design and analysis should be coded in FORTRAN. The compiler chosen for compilation of the programs in Windows NT environment was Microsoft Power Station (ver. 4.0) which was considered advantageous compared to Salford FORTRAN.

### 4- System organisation

The proposed system consists of three main modules each undertaking a part of the intended design procedure as depicted in Fig. 1. The input to the system is in the form of drawing files in which functional spaces are defined as rectangles by their four vertices. The sketch or drawing is initially prepared in AutoCAD consisting of a number of "polylines".

The first module in the system is the structural layout generator (SLG). This module performs initial geometrical manipulations for all floors in the realm of architecture, i.e. it establishes the geometry of the building, sets architectural grids, and prepares various lists of entities including polylines, gridlines and nodes. The module then performs a process of allocating nodes in each floor, applying various rules resulted from different structural constraints. This module finally generates data required by the analysis and design module that includes the configuration of all planar frames and loadings.

The structural analysis and design module (SAD) designs the structural elements using an approximate but well established method referred to as the "wind moment" method (Anderson et al 1991). The detailing of the structure can then be carried out according to the output of the approximate design. The wind moment method is explained in Appendix 1.

The costing module (COST) makes an estimate of the costs using the technical specification of the structural elements as provided by SAD. It calculates the weight of the steelwork and fabrication costs, and outputs bills of quantities and cost estimates. The cost of a particular design resulting from a set of parameters determined by the user during the design process is stored to be compared with later cost estimates generated by running the system with other sets of parameters.
A further module controls the execution of the programs and the data flow between the programs. The data management and storage system is based on the concept of project data and common data. The former includes the building geometry, CAD data, input/output data and solution data. The latter consists of libraries of computational, detailing and estimating data. The database system is shown in Fig. 2. The architecture of the system allows links to commercial database systems through SQL facility provided by the CAD application. The graphical user interface and dialogue boxes have been designed so that a student can interact with the system in a user-friendly manner, and learn through communicating with computer. "Help" and "Information" buttons in dialogue boxes display text and images to help student in comprehending the design process.

5- Summary and conclusion

A computer-assisted learning system has been described that enables students of architecture to draw sketches of spatial layouts in AutoCAD, generate a structural form, and design the structural components. With this system, the students are able to examine the structural layout of the building, the member sizes (and even the connections between members if so wish) as well as an estimate of the fabrication and erection cost of the building. They can change the design parameters on which the layout of functional spaces were based, and, by generating the new structural layout, as run the program, examine the effect of the changes that have been made. A cost estimate can be produced by running the costing module to be used for an assessment of the design.

The system provides students with a tool by which they can examine the effects of the decisions they make at the initial stages of design on the structure of the building, and observe how the architectural design of a building may be influenced by its structural arrangement. They can also familiarise themselves with the process of structural design without being concerned with tedious calculations. Furthermore, they gain a general understanding of the use of structural steelwork.

An important feature of the system is that each of its modules may be run independently of the others, and the user may enter and exit the system in any stage at will. Each program has been verified independently and the whole system has been tested on buildings with varying degrees of complexity. However, the system is limited to regular multistorey buildings. The system needs to be tested in courses such as building technology, architectural structures, strategic design, integrated building design, and CAAD. Future developments, based on the feedback from its experimental use, will improve the usability and remove some limitations of the proposed environment.

References


Howes J. (1994)
"CAD Education and Practice in the UK", The Virtual Studio, Proceedings of the 12th Conference of ECAADE, Glasgow, UK

MacCallum & Hanna R. (1996)

Martini K. (1996)


"A World-wide Questionnaire Survey on the Use of Computers in Architectural Education", 15th ECAADE '97 Conference: Challenges of the Future, Vienna University of Technology, Austria

"A structural engineering education image database", Proc. 5th ASCE Int. Conf. Computing in Civil and Building Engineering, pp. 447-54

1 By structural continuity it is meant that, for instance, structural walls in upper floors are carried by the lower floor ones, or upper floor columns are continued through the lower floors to the foundation.

2 The European countries surveyed include the Netherlands, Sweden and the UK.

3 Education in Computer Aided Architectural Design in Europe.

4 The Association for Computer Aided Design.

5 AutoCAD has announced that Windows NT is their preferred environment for their future developments. (http://Autodesk.co.uk)

6 Windows NT is a 32-bit system. 32-bit systems can provide application with access to sophisticated features, including memory management, window management, graphics support, networking, security, multitasking, threading and symmetric multiprocessing (SMP). http://Microsoft.co.uk

7 The latter had not originally been developed for windowing, and such features have later been added, while the former should run smoothly under Microsoft Windows.

---

**Fig. 1, The outline of the system**
Appendix 1: The Wind Moment Method

Where a steel frame is unbraced, an established technique is to rely on the rotational stiffness of the connections to provide resistance to wind, even though such restraint is ignored under the action of gravity loads. This approach is termed the "wind-moment" or "wind-connection" method. In its usual form the method assumes:

1) under gravity load, the connections act as pins (Fig. (a)),

2) under wind load, the connections behave as rigid joints, with points of contraflexure at the mid-height of columns and mid-length of beams (Fig. (b)).
Members and connections are proportioned initially to withstand gravity load. The internal forces and moments due to gravity load and wind are then combined in appropriate load cases. The design for strength is completed by assigning section sizes. For serviceability, sway deflections are calculated assuming connections are rigid.

The advantage of this method is its simplicity. As the frame is rendered statically determinate, internal moments and forces are not dependent on the relative stiffnesses of the members. The need to repeat the analysis to correspond to changed section sizes is thereby avoided. Consequently, the method has been used extensively in design offices, and is recognised by most of the codes of practice. The justification of the method has been partly due to the fact that buildings designed on this basis have proved satisfactory in use.

*Fig. (a) Frame under gravity load*  
*Fig. (b) Frame under wind load*