INTEGRATION OF COMPUTER BASED MODELLING AND AN INTER-DISCIPLINARY BASED APPROACH TO BUILDING DESIGN IN POST-GRADUATE EDUCATION

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ABSTRACT

Computer based design aids have much potential to improve the productivity of the design process and provide more confidence in the performance of a building. Although sophisticated design aids have existed for some time there is still a reluctance to use them to full advantage. This is particularly true of the strategic phase of building design. The barriers to the use of computer models are explored and the means by which they can be overcome via the education of post-graduate students and practising professionals are discussed.

1. INTRODUCTION

The basic procedures involved in the design of a commodity are the same whether it be a toaster, supersonic passenger aircraft or a building. These are illustrated in figure 1. The key to any design methodology is the setting of the design brief, which implies the need to gather and consider information to implement the client's wishes. For buildings the analysis of this information may begin with a consideration of existing stereotypes and constraints may be imposed by the requirements of aesthetics, economy, ergonomics, comfort and safety. A single or preferably a number of potential design solutions will be developed or synthesised in response to the design brief.

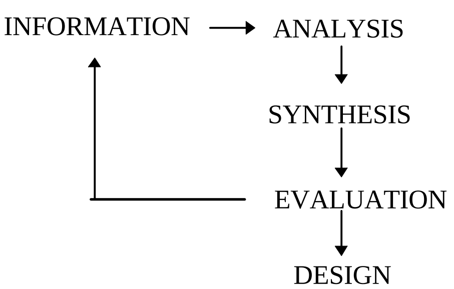

Figure 1. Simple model of the design process.

If on examination, the design solutions do not satisfy all the implied criteria specified in the brief, or fail to comply with regulatory requirements then the basis on which the solution was developed will have to be reconsidered. A feedback process is inferred where further information or additional expertise might be required with a subsequent re-analysis and synthesis of modified or even new design solutions.

This design methodology illustrates the need for feedback and the essentially circuitous nature of the process. However, if the productivity of the process is to be maintained or enhanced the number of feedback loops needs to be contained. If too many loops are generated, because of poor synthesis or evaluation procedures, then the productivity of the process will be seriously impaired.

The Royal Institute of British Architects (RIBA) developed a "plan of work" [1] as a management tool for building design. This is outlined in figure 2 and suggests that two distinct phases exist within the design process, **strategic** and **tactical**. The needs, structures and organisation of interdisciplinary communication, and the types of design tool required, are likely to differ with regard to the nature of the activities undertaken within these phases of the process.

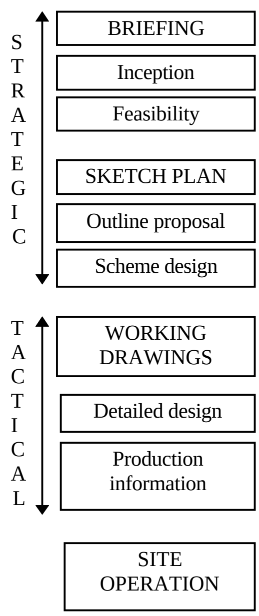

Figure 2. Outline of the RIBA "Plan of Work" stages. [1]

Ideally the strategic phase comprises the development and examination of design ideas arising from the requirements of the brief, the experience of the designers, and the information, fashions and ideas current at the time. The feasibility of new ideas or the application of new technologies will be examined and their potential assessed. The fitness of a number of possible solutions will be evaluated and modified. Towards the end of this process a choice will be made as to which scheme will go forward for continued development into the final building. A scheme design will follow, from which detailed drawings will be developed and calculations made for specific aspects of the design. The project has now entered the tactical design phase and individual systems will be considered in greater detail. This will include the sizing and design of the building services.

Within both the strategic and tactical phases, design aids and tools have always been utilised in an attempt to improve the productivity of the process and to increase the designer's confidence that the proposed solutions will be fit for their purpose. However, many designers are anxious at the speed with which computer based design tools have been developed and consequently are concerned that they may be less valid or safe than the well tried traditional methods.

The significance of and the utility provided by many of the concepts and physical modelling techniques applied in modern computer design aids may not be understood by some members of the team. The difference between steady state and dynamic thermal performance of buildings and building components is a good example of this. Also, many professionals see computer design aids as a threat to their own expertise and knowledge and thus to the salaries that they command. Consequently, it is important that the concepts involved in these design aids are understood as well as their merits and limitations.

Design requires the assimilation of often disparate elements which may interact in a variety of complex ways. Representations of the process of design such as those in figures 1 and 2 suggest that it is possible to reduce these interactions to ordered forms. However, such models cannot make reference to the possibility of intuitive action or the "creative leap" which is so often a characteristic of design. Creativity does not operate from a knowledge vacuum but is a process which perceives or joins existing bodies of knowledge in new ways. Computer tools developed to aid decision making during design should be structured to allow the team realistically to exert adequate control and influence over the process. They must fully enhance the use of the creative talents of all the members of the design team.

The design and development of most commodities requires interaction between team members with very different skills from various professions. This is particularly true regarding the design of modern buildings. The multi-disciplinary nature of the design team requires good channels of communication to ensure that one design team member's decision does not become another's problem. Inadequate channels of communication lead to an increase in the number of process loops undertaken before the design is brought to completion.

In the UK, the present design procedures have existed and developed since the 19th century. Thus the modes of interaction between professionals, and the sequences of decision making, mostly have remained unchanged for many years. Much of this experience has been encapsulated in the RIBA "Plan of Work" [1]. The structured approach to building design outlined in the plan of work implies a greater degree of inter-professional consultation than often occurs in practice. Traditionally, a design team arrangement will be as shown in figure 3.

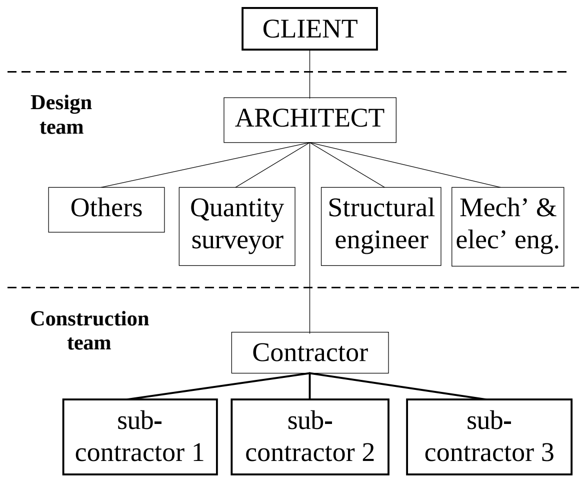

Figure 3. Typical design team arrangement.

An inherent risk with this hierarchical structure is that only the architect, acting as team leader enjoys a close relationship with the client. For the other members of the team it often seems that the communication route is one-way, from the architect. As buildings become more complex this top-down approach to design is likely to result in inefficient design methodologies where the feedback loop from evaluation to analysis is initiated excessively frequently. An interdisciplinary approach to design where all the relevant professions are represented from the inception stage is becoming essential in order that a more linear process may be maintained servicing the parallel needs of all the design team members. An alternative arrangement of the interactions between design professionals could be as displayed in figure 4.

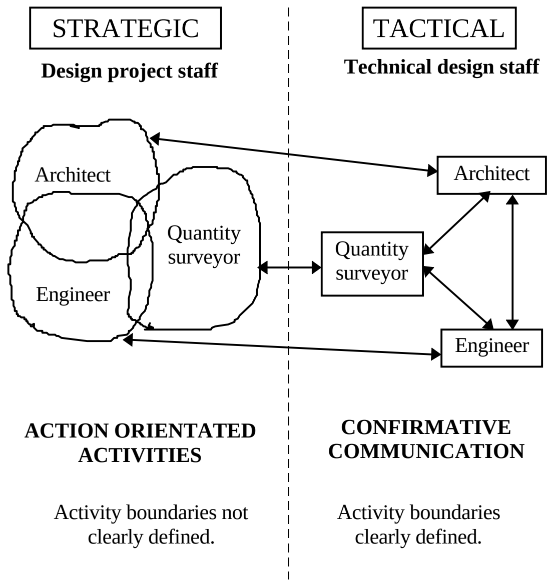

Figure 4. The design process and communication within the design team.

Although a project manager will be required, this structure is less hierarchical and communication links would be regarded as important throughout the whole process. At present even the most sophisticated design tools tend to be very discipline specific and often reduce rather than enhance the opportunities for interdisciplinary, interactive design activities. Generally, the greatest barrier to the adoption of these design tools in practice is a poor understanding of their capabilities on the part of the design team, a lack of common understanding or language between the various professions regarding the design process and a poor understanding of the design process on the part of software developers. The manner in which these tools are used is an important aspect with regard to their usefulness and the development of methodologies which take account of the needs of the design process is essential.

Potentially, sophisticated computer based design aids can improve the productivity of the strategic phase of the design process through the rapid evaluation of design options.

2. COMPUTER MODELLING - AN EDUCATIONAL RESPONSE

Individuals and teams will always demand the right to work in the manner which they consider suits them best. However, on examination many separate modes of working contain common features. If design aids are to be used effectively then a framework for their application within the design process must be recognised and developed. The integration of computer based modelling and simulation in the education of building industry professionals has been a central feature of the post-graduate, one year MSc course in Energy and the Built Environment at Cranfield University, for the past ten years. The course is provided for architects, building services engineers, structural engineers, planners and surveyors in order to encourage a common involvement with energy use in buildings and to promote the concept of inter-disciplinary building design.

Students study the subject of energy and the built environment across a wide subject spectrum; energy supply and use, political and environmental aspects of energy use, heat transfer and recovery, solar energy technology, building design and construction, climate respecting design, building services and controls, thermal and visual comfort and indoor air quality. They then move on to put this knowledge into practice, working in multi-disciplinary teams, firstly on small scale building design projects, of two days duration, and then on a larger building design project lasting for eight weeks.

For the smaller projects, the students make use of steady state thermal and daylighting simulation models to provide them with rapid feedback on the effects of their design decisions. These exercises provide them with experience of the integration of simulation results into the design development process, group decision making, task allocation and the presentation of the final design.

With the experience gained from these small projects the students then move on to the larger building design project. For this exercise the students are briefed as for a live building project, by a representative of the client organisation, on the client’s requirements and the site for the building. The students then proceed with the design of the building, making use of the fully dynamic, computer based thermal modelling and simulation program, ‘Tas’ [Thermal Analysis System].

The Tas system, was developed originally in the Department of Applied Energy at Cranfield Institute of Technology [now Cranfield University] and is now owned by Environmental Design Solutions Ltd,

[EDSL] who use the system commercially and continue to develop and distribute the software [3]. The system comprises of several component programs, which combine together to provide a dynamic simulation of the heat transfer processes taking place in the building under test. This system is used at all stages of the student's design process, in order to explore the three dimensional aspects of their design proposals and the relationships and interactions of spaces, internal environments, construction and finishing materials, climate and site conditions.

The first stage of the design process involves an analysis of the site, the client's requirements and any further necessary research. The thermal simulation program can be useful even at this early stage, as the geometry of the site and surrounding buildings can be entered in the program and graphical plots obtained of the shading of the site by the surrounding buildings.

Students are encouraged to analyse the spatial accommodation requirements; size, shape, volume, connections and interactions by the use of 'bubble' diagrams. These are extended into a further dimension; the identification of the environmental requirements of the spaces such as preferred temperatures, daylighting levels and acoustic considerations. Accommodation can then be grouped and positioned by environmental as well as functional requirements and interactions. These processes of analysis and synthesis form the basis of simple exploratory models entered into the thermal analysis programs. This second stage of the design process is treated as a critical phase, in which students develop a strategy for their design by the evaluation of conceptual sketch proposals. To assist in this process, they use the Tas thermal simulation program in order to make basic assessments of the effect of orientation, glazing type and area, construction materials, building use and occupancy on the thermal comfort of the occupants and on energy usage for space heating and possibly air conditioning. The effect of the proposed building on surrounding buildings can also be assessed.

This opportunity for early evaluation of sketch proposals provided by the thermal simulation program, is considered to be a very significant part of the process of building design and of the students learning experience.

In the '3d-Tas' program the building form is entered floor by floor, perspectives and elevations can be produced in order to display the resulting model. The building model is then divided into zones on the basis of occupancy, heating and cooling requirements, orientation etc., which need individual or collective consideration during the thermal simulation process. Building elements are designated, according to different materials or combinations of materials occurring in the roofs, ground and intermediate floors and internal and external walls. At this early stage, external glazing can be designated by entering the percentage of external surfaces to be glazed. This allows rapid evaluation of the effects of glazing areas and orientation on the internal thermal environment. The latitude and orientation of the model are set as required but can be changed for later comparative simulations.

Shadow calculations can be performed, on the three-dimensional model, which plot the path of solar radiation incident on the building for periods up to a whole year. Sunlight and shading patterns can also be displayed graphically on the perspective and elevational views of the model.

In the 'A-Tas' program, building constructions made up from layers of appropriate materials, are applied to the designated building elements

Internal conditions files can be set up for each of the designated zones for particular days of the week or times of the year. The internal conditions indicate the quantity of internal gains, to be taken into account during the simulations, from the rates of sensible and latent heat output from occupants, lighting and equipment and the duration of these outputs. The requirements for heating and cooling plant, set points, controls and periods of operation are also entered as are air infiltration and mechanical ventilation rates.

Thermal simulations can then be performed for either one day or for any period up to a year, utilising an appropriate weatherfile selected from the database.

Students are encouraged to keep the computer models as simple as possible during this strategic stage of the design process so that the performance of a range of combinations of built form, orientation and building materials can rapidly be assessed and compared. The table in figure 5 indicates how a matrix of combinations can easily lead to a large number of simulations requiring careful tabulation and recording of results.

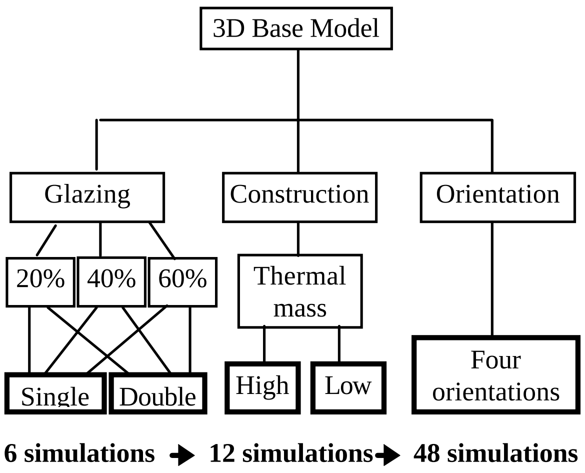

Figure 5 Development of a simulation matrix

In building types which involve repetitive grouping of accommodation such as schools, offices, hospitals or residential accommodation, a representative part of the accommodation can be modelled to provide adequate feedback in the early evaluation stages of the design process as figure 6.

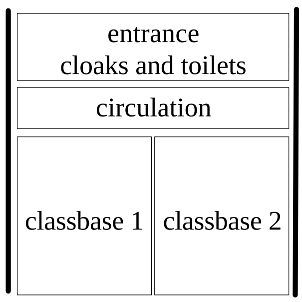

Figure 6 Typical repeated classroom arrangement

The results of the one day simulations include hourly results for each zone in terms of internal air, mean radiant and resultant temperature and hourly heating and cooling loads. The results from the longer batch simulations provide heating and cooling loads and solar gain per zone, per month. The results of temperature checks can also be obtained. These give the number of hours and days within the simulation period when the air temperature in each zone exceeded levels, set by the operator, during certain times of day.

Using other simulation programs, the daylighting and artificial lighting requirements of the proposed buildings can be explored and fed back into the thermal simulations in an iterative process. In the thermal analysis program windows, doors and other ventilation openings can be sized, positioned and periods of opening scheduled. Detailed studies on the effect of shading devices, heating and ventilation plant and control mechanisms can also be brought into the investigation.

In all, the students present the development of their building design at four stages of the design process, to a group of assessors including the client representative.

A valuable aspect of the design exercise is the management of the simulation process; the initial use of simple models in early decision making, the simulation of representative parts of the accommodation rather than the whole building, the setting up of matrices of variable design elements to be tested and the quantitative evaluation of the simulation results. By working through these simulation based investigations, students are able to evaluate the interaction between the different components which make up the thermal or visual performance of a building and so develop a deeper understanding of the thermal behaviour of buildings, the building design process and an appreciation of the skills of different members of the design team.

This understanding of the abilities and methods of the various professions and a willingness to participate in multi-disciplinary working, aided by computer modelling, is a valuable asset in the creation of buildings which satisfy clients and building users and meet environmental requirements.

Attempts have been made to move these ideas on from the educational world into the realm of professional practice. On two occasions the department has facilitated the working of a multi-disciplinary design team consisting of practising architects, building services and structural engineers, interior designers, landscape architects and client representatives. In each case the project involved the design of a Primary School for a local authority.

Conclusions from the first exercise were very positive in terms of the final building design, the extent of inter-disciplinary working and the use of the computer based simulation methods. The second exercise was less successful [2]; an unwillingness was indicated by some of the participants, possibly through lack of experience, to contribute to the team based, exploratory approach to the design process using computer based methods. This indicated that putting a multi-disciplinary team together does not necessarily lead to inter-disciplinary working. Both exercises showed the importance of the management role in inter-disciplinary working.

3. CONCLUSIONS

These experiences, reinforce the need for discussion within the building industry of the use of computer based simulation methods from the earliest stages of the building design process, and the integration of computer based modelling and simulation techniques into the training of the members of the building design team.

Neither post-graduate students nor practising professionals have an innate understanding of the manner in which computer based modelling can be applied to building design. Consequently, an urgent educational need exists to provide training.

REFERENCES

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[3] Environmental Design Solutions Ltd,
13/14 Cofferidge Close, Stony Stratford, Milton Keynes, MK11, Buckinghamshire, UK.