THE INTEGRATED DESIGN AND CONTROL OF BUILDINGS

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ABSTRACT

CAD manufacturers are providing an increasing amount of integrated building design software. These integrated CAD systems have few, if any, facilities to assess building performance. The building design profession is increasing its use of performance assessment tools for traditional and refurbishment design and not just technologically advanced design. Performance assessment tools will continue to grow in importance as building technology moves towards providing Intelligent Buildings.

This paper will describe a current project aimed at providing a suite of computer-based tools which constitute an Integrated Building Design System capable of integrating the building design processes. This software system is called BIDS and is based upon dynamic simulation software for assessing building performance integrated with other software tools such as CAD systems.

BIDS offers the construction industry a whole life-cycle solution to building design and operation. BIDS achieves this by:

- being used throughout the design process by the architect and other design team members operating on a single model of the building.
- upon completion, the design information contained within the BIDS system will be used to help commission the building
- the use of the BIDS system continues through the building's life forming the basis of an intelligent control system for the building.

INTRODUCTION

Many of the leading CAD systems are providing integrated building design related software. Notwithstanding the obvious advantages of this integrated software, the software is geared towards the production aspects of design eg providing plans and elevations; pipe and duct sizes; cable sizing; and so on. This development conforms to current design practices with minimal consideration of the evolution of building design towards Intelligent Buildings or attempting to assess how the design will actually perform.

The major barriers to the design, construction and operation of what can be termed "Intelligent Buildings" are: the inability of the design team to assess the performance of new technologies and control systems and their interaction; and the need for a new generation of Building Management Systems capable of reacting to changes in both the external and internal environments associated with a building in a fully integrated way.

The BIDS (Building Integrated Design Software) system attempts to overcome these problems. BIDS is based upon dynamic simulation software for assessing building performance integrated with other software tools such as CAD systems which, in effect, act as the front-end tools for the performance assessment software.

BIDS offers the construction industry a whole life-cycle solution to building design and operation. BIDS achieves this by:

- the design team operating on a single model of the building throughout the design process
- upon completion, the building model is used to help commission the building
- the model is then used as the basis of an intelligent control system for the building

This intelligent control system is developed using the same dynamic simulation software which was used to design the building. The dynamic software will simulate the building in real time, being continually updated by sensor information. If some control action is requested the BIDS system will predict the consequences of various control scenarios and select the most efficient option.

As well as describing the reasons why such a system is needed, this paper will describe the components of the BIDS system; how the system is used to intelligently control buildings; and the available software tools for the project.

THE NEED FOR AN INTEGRATED BUILDING DESIGN SYSTEM

Building Design

Evolutionary Design Every building design is theoretically unique. Historically, building design has developed through physical modelling; the experience gained by architects and engineers from the design process plus feedback on how the building performed is applied to improve the next design. Therefore, designers gain experience, then apply that experience in particular areas and becoming expert. This experience permits designers to make better intuitive or informed decisions, based on their experience or on information obtained from sources including building-related magazines and specialised handbooks and product catalogues. This design process is evolutionary: however this process neither eliminates bad buildings nor suppresses good innovative design.

Today we have a situation where advances in building technology and design concepts are outstripping the designers ability to gain experience of their impact on building performance. A recent, and current example of this is Atrium Design. To tackle this problem it is essential for the design decision making to be more integrated, with the design team understanding and discussing the implications of their design decisions with other members of the design team. Until this is successfully achieved it will remain difficult to effectively incorporate new technologies and design concepts in buildings. Problems will occur until new techniques such as the BIDS system are available which actively promote an integrated approach by the design team.

Static Buildings The clothing we wear depends largely on how we perceive our comfort requirements relative to weather, activity and setting. We modify our state of dress to ensure we remain comfortable. Building envelopes, as a further protection from the external environment, remain fixed. Buildings have few features which will permit them to respond to internal or external environmental changes, eg window blinds. Even in a 'static' built form one would expect a building's envelope to be very different on the north side vs. the south side. Given the dynamic nature of light, solar energy, wind and rain, unchangeable buildings can not take full advantage of beneficial natural elements, and thus have to be over-designed to protect the building and occupants from the varying external environment.

This building philosophy is based upon limitless and cheap earth resources: oil, gas, water, etc. The greater public concern for the environment (eg ozone depletion, water pollution, acid rain, the greenhouse effect) has focused public attention on the preservation of earth resources. There is an increasing attempt by the more progressive designers and clients to make buildings more environmentally friendly by reducing the earth resources consumed by a building during construction and operation.

A building envelope designed to be in harmony with nature and the building occupants would have to be dynamically responsive to both internal and external environmental changes to the building. Building technology has advanced to the stage where 'dynamic' or intelligent buildings can be designed which respond to climatic changes through interaction with local microclimate, by altering exposure to desirable and undesirable conditions. These intelligent buildings by nature have to be efficiently designed.

New Building Technologies Intelligent buildings can be constructed by incorporating new building technologies such as Transparent Insulation Materials; Passive and Active solar devices; Holography; Photovoltaics; sophisticated energy recovery systems; movable insulation; and phase change and other storage media. These new materials in some cases can spontaneously react to environmental change, providing a dynamically interactive envelope, for example electrochromatic glasses. Alternatively, the building can have devices incorporated which react through sensors to alter interior cooling, heating and lighting conditions to meet the occupant and building needs.

With the increasing availability of new building materials and equipment plus the increased demand for better buildings will result in the dramatic increase in the role of specialised consultants to the design team such as facade experts, control experts, etc.

Design assessment techniques Currently the design team may work on a series of simple, software specific, models. However, the complexity of the interactions between design or operational variables is such that computerised traditional design tools cannot adequately provide the information necessary to conduct an assessment of building performance. Therefore in many instances, due to the poor quality of relevant performance information, designers must rely on their intuition when making design decisions.

There is an increasing demand for performance simulation over many variables rather than traditional calculation techniques. Simulation tools are required to provide a fuller understanding and insight of the design problems. For instance, the design team should be capable of assessing the effects of a particular facade on the interaction between artificial lighting and the heating/cooling requirements of a building in all climatic conditions. This would enable the HVAC plant to be most cost effectively sized.

The BIDS system allows the client and his design team to explore all of these parameters (using precise simulation) and arrive at the correct solution without guesswork or rules of thumb.

COMMISSIONING/CONTROL

One major problem in buildings is their commissioning. Many buildings are poorly commissioned and never perform as they were originally intended. As buildings become more sophisticated it will be vital to have properly commissioned buildings.

One impact of the microelectronics revolution on the Construction industry has been the use of the term "Intelligent Building" applied to describe any building which employs some feature, such as a Building Management System (BMS), to control the building. Whilst this is obviously a considerable improvement in controlling buildings, the building cannot be termed "Intelligent" because these control systems are based upon simple algorithms which do not consider the implications of their actions on the whole building.

BUILDING OCCUPATION

There is a greater demand and expectation, by building owners and occupants, for increased quality of environment.

Current definitions of occupant comfort are based on statistically determined averages developed from laboratory experiments. It is common knowledge that an 'average' person does not exist. Individuals needs vary and change daily, even hourly, depending on age, sex, clothing, level of activity and many other variables. Therefore it is difficult with current technology to satisfy the psychological, physiological and physical needs of each occupant, particularly when most designs are geared to produce homogeneous conditions which the individual must accept. Simulation is required to assess in detail the effects of the varying internal environmental conditions upon building occupants.

Not only is the comfort of the occupants important but so is their health. For example the quality of air is very important to ensure the occupants are neither drowsy nor ill.

The consequences of having an increased absenteeism can be significantly high compared with the cost of ensuring the design is satisfactory. Buildings with a higher level of absenteeism are frequently referred to as "Sick Buildings". The Sick Building Syndrome is not a manifestation of bad design but a lack of performance assessment information. Because designers do not use simulation tools they are unaware of the consequences on the health and comfort of the building occupants.

BUILDING REFURBISHMENT

Designers can no longer rely on the fact that the original function of a building, its occupancy characteristics, use, or purpose will remain as defined during the design stage. A building will undergo at least one major refurbishment, for whatever reason, during its lifetime. The rate at which the interior of a building is renovated, changed, reconfigured, and re-designed is called the 'churn-rate'; IBM's churn-rate in the US is three years. In addition, the performance of a building can change dramatically due to the effect of new technologies introduced into the building's fabric and the microclimate of the building which changes as old buildings are demolished and new ones built.

In these cases the BIDS system can readily evaluate the effects of any changes on building performance.

Future Design Practice

Increasingly there are attempts to design highly responsive building envelopes. Additionally, designing the internal environment of a building for the average person, which is wasteful of resources and should be replaced, where appropriate, by a personally controllable environment which will:

- be inoperative when not occupied or used,
- be used in fixed or mobile situations,
- respond immediately to changing conditions,
- sense if the region serviced is occupied by more than one individual,
- and, be free-standing, integrated with furnishings, and/or integrated with other environmental comfort systems.

What is being suggested is a truly responsive architecture, dynamic in its performance and form, adaptable to its microclimate and interactive with the occupant. To achieve these objectives requires that:

1 the design team operate in an integrated way
2 dynamic simulation tools are available to conduct performance assessments
3 it is possible to intelligently control buildings

COMPONENTS OF THE BIDS SYSTEM

In order to make improvements in our built environment we need to use a holistic approach to the design of our spaces and places.

The Integrated Building Design System, BIDS, is intended to be used throughout the full life-cycle of the building: from concept to demolition. The BIDS system will help provide the clients design brief and then support the design team from the initial sketch design phase, through to detailed design and construction. During this design process the design team will work on a single integrated model of the building. The model consists of different layers of design data attributed to the building geometry.

During the design phases the design team will be supported by a software 'Design Supervisor' which would know the function of the software tools available to the design team and invoke them, when appropriate, to answer design questions. As a further aid to the design team, the Design Supervisor will be linked to a multi-media environment consisting of computer graphics, animation, sound, video and literature providing information on case studies, expert opinion, design philosophy and design options.

The information on the building contained within the BIDS model is used to more rapidly commission the building and the monitored information from the building used to commission the model. When both building and model are synchronized the model is employed to control all operations within the building, thereby creating a 'brain' for the building and the first possibility of controlling truly intelligent buildings.

Upon occupancy the model and multi-media are used by the building manager to understand how the building operates and provide full facilities management capabilities.

The elements of the BIDS system are now described in more detail.

The Design Brief

From the design brief the basic constraints or limitations with which the design team should operate are defined in terms of areas, number of occupants, function, capital or running cost, environment requirements, etc. This brief will be used initially by the architect to establish the building topology and by the services engineers to generate their strategies. Operating within these constraints the design is built up iteratively by checking aspects of the design both qualitatively and or quantitatively depending upon the issue under evaluation.

An expert system design brief specification tool is required for the BIDS system to ensure the objectives of the client are clear. The design brief can be permitted to alter in the light of information or results from the conceptual or detailed simulation modelling of the building.

Model Data

To ensure design team integration the design team will operate with a single data structure representing the detailed data description of the building, and not a series of smaller, software specific, data structures. This will greatly reduce frequent input of the same information, or errors due to mismatched data.

Data associated within the model can be sub-divided into three classifications:

- boundary conditions, eg site, climate, costs of raw material
- design variables which are controlled by the designer, eg fabric, structure, HVAC plant
- performance values resulting from specific evaluation of the interaction of boundary conditions and design variables, eg climate and fabric on energy consumption

Obviously performance values can become boundary conditions for other design variables eg the amount of fresh air to maintain comfort conditions will be used as a boundary condition in performing duct sizing calculations.

Dynamic Simulation

The BIDS system will consist of a CADD system, design calculation tools and dynamic simulation software tools. It is essential for building design that there are software tools which are capable of simulating the highly dynamic nature of the building.

Most, if not all, performance assessments are computable, and thus suitable for computer implementation. During the past two decades, computer based building performance analysis applications have been developed and used in research-oriented institutions, being continuously enhanced to improve modelling capabilities and increasing accuracy. Performance assessment simulation is the most effective tool to assist designers in making design decisions. As the capacity and power of computers increase the greater will be the interactive feedback.

BIDS will include a library of software tools which will be activated at the designer's request to determine the value of the corresponding performance variable. If the boundary conditions or design variables have not been specified, the BIDS system will request the information from the designer.

One of these tools will conduct building energy simulation enabling a user to quickly answer such design questions as:

- what, and when, are the peak building or plant loads and what are the rank-ordered causal energy flows?
- what will be the effect of some design change, such as increasing wall insulation, changing the glazing type or distribution, re-zoning the building, re-configuring the building, re-configuring the plant or changing the control regime?
- what is the optimum plant start time or the most effective algorithm for weather anticipation?
- how will comfort levels vary throughout the building?
- how will temperature stratification, in terms of zone sensor and terminal unit location, affect energy consumption and comfort control?
- what contribution does building infiltration and zone coupled air flow make to the total boiler or chiller load and how can this be minimised?
- what is the contribution (to energy saving) of a range of passive solar features?
- what is the optimum arrangement of constructional elements to encourage good load levelling and hence efficient plant operation?
- what are the energy consequences of non-compliance with prescriptive energy regulations or, conversely, how should a design be modified to come within some deemed-to-satisfy performance target?
- which heat recovery system performs best under a range of typical operating conditions?

and so on. This capability provides the designer with a tool to more fully understand the interrelationships between design variables and performance parameters, to then identify potential problem areas, and so implement and test appropriate building, plant and/or control modifications. The resulting design is more energy conscious with better comfort levels attained throughout.

Immediately such a design tool is installed, it is inevitable that commercial pressures will seek to maximise the return from such an investment. Design horizons will be widened; design challenges will be increased. Issues that were once peripheral to run-of-the-mill plant sizing tasks are likely to assume considerable importance.

Other simulation tools will be invoked to provide additional information, for example:

Computational fluid dynamic studies of air flow to answer questions such as:

- can smoke spread under fire conditions be contained safely?
- how will the design perform in terms of air distribution, temperature profiles and velocity characteristics?
- what are the optimum supply and extract conditions?
- how far will contaminants travel and what are the concentration levels likely to be?
- how will buoyancy driven airflows influence the airflow pattern?

Lighting simulation is required to answer:

- what will be the impact of mixed natural/artificial lighting on the internal environment?
- what will be the visual effect of alternative lighting strategies, surface finishes and colour schemes?
- effectiveness of task lighting?
- 'what-if' parametric studies of design alternatives such as luminaire placement
- effects of diversified lighting loads on energy demand
- supplementary background/security lighting

Acoustics simulation software is required to answer questions such as:

- will internal or external noise pose a problem to occupant comfort?
- does the decibel level within the space conform to regulations and/or acceptable values for the function of the space?

And tools must be available to visualise the building in order to:

- visualise the TOTAL building design, in three dimensions, in colour and in the context of the surrounding landscape?
- animate a 'fly-round' onto video tape? Either simply for design checking or at a corporate-level presentation standard?
- create high standard design presentation material for both clients and public enquiry/planning tasks,
- applied to design security solutions for the building.

These simulation tools are available.

Design Supervisor

The design team identify the problem, generate design solutions from the permissible options, and evaluates them. However, the total impact of the decisions taken must be viewed against both the design brief and the consequences for other members of the design team. It is important for the design team to maximise the benefits of BIDS that a design support tool is provided as part of the BIDS system. This will take the form of an expert system or 'design supervisor'. The 'design supervisor' will co-ordinate the communication between the design team, the model data, and the software tools. The 'design supervisor' consists of two components:

- knowledge of both the model data structure and the software tools available. It continuously monitors every design decision ie interaction with the model data and informs the appropriate design team members of any proposed changes to a model which may have an effect on the building design.

- a multi-media system consisting of computer graphics, animation, sound, video and literature providing information on how to use the BIDS system plus case studies, expert opinion, design philosophy, design options, industry handbooks and product catalogues. This system will allow the designer to explore and understand specific topics. BIDS will store design decisions and solutions in the multi-media system for access by all members of the design team.

An example of the 'design supervisor' operation follows. If an architect wished to change the external glazing to a heat absorbing glass then a simple change is required to the model data. However, the first order effects of this design change are:

- the daylight may change and therefore artificial lighting may alter;
- occupant comfort may change because the mean radiant temperature in the space will be higher;
- the downdrafting effects from the window may change;
- the heating and cooling requirements of the space will change.

Each first order effect will have second order effects: for example consider the fact that heating and cooling requirements will change - this may affect pipe and duct sizes, which may in turn affect ceiling voids, which may affect floor to ceiling heights and therefore capital cost of building. In parallel it may change the size of the central plant, resulting in smaller/larger plant room; if plant room too large it may have to be situated in a different part of the building; and capital and running costs of the plant will change.

The BIDS 'design supervisor' is capable of investigating any number of single first order evaluations of the building performance. Only after the decision is taken, will the model data be updated.

INTELLIGENT CONTROL OF BUILDINGS

Just as buildings with indoor plumbing, electric Lights, and air conditioning are not necessarily healthy buildings, buildings containing intelligent technologies are not necessarily intelligent. An Intelligent Building may be significantly different in its form, quality and performance, compared to current architectural forms.

The Intelligent Buildings Institute in Washington DC defines an Intelligent Building (IB) as:

> '...one which integrates various systems (such as lighting, HVAC, voice and data communications, and other building functions) to effectively manage resources in a co-ordinated mode to maximise: occupant performance, investment and operating cost-savings, and flexibility. Various levels of intelligence are provided through interactive controls and communications devices driven by either central or distributed micro-chip intelligence, and employing sensing devices and interactive distribution media.' (IBI, 1986).

The majority of existing Intelligent Buildings are those in which Information Technology is employed for improved efficiency and competitiveness. However, the type of Intelligent Building described earlier will come, it is simply progress. These buildings will be highly engineered and require the highest level of design team co-ordination to ensure the design is correct.

For the purposes of this paper an Intelligent Building is defined as having three elements which make the building Intelligent:

1 the controls of all the systems in a building, whilst retaining their own integral intelligence, are linked to all others as described above.

2 the building will require the ability to respond to any changes in the internal and/or external environment, which necessitates the use of new building technologies.

3 the most important feature of an Intelligent Building will be a tool to integrate 1 and 2 above. This will be a dynamic simulation tool which can supervise the control system and coordinate the use of the buildings 'dynamic' features to ensure optimum performance in terms of occupant comfort, energy consumption, etc.

The BIDS system contains both the model and a wide range of simulation tools which can be used both to dynamically control the building. This is the next generation of Intelligent Controllers of Buildings, which are built upon predictive simulation capabilities rather than empirical relationships. In operation the software will use the model information and sensor data to predict ahead and take appropriate action thereby optimise the building operation in terms of occupant comfort and energy consumption.

SOFTWARE TOOLS

The BIDS suite of software will be assembled from three sources: ASL, CAD systems and third party specialists.

The Autocad and Intergraph CAD systems will be the first to be offered as part of BIDS. The CAD system is used as the basic tool for setting up a database containing all the model information pertaining to the design. All design calculation and simulation evaluation software will select the necessary information from the database. Where there

is insufficient data available, the user will be offered intelligent defaults or the opportunity to augment the database with whatever information is required.

ASL will provide four simulation tools to BIDS:

Building Energy Simulation

This software is a fully interactive, rigorous simulation system which is capable of modelling the energy and fluid flows within combined building and plant systems when constrained to conform to control action.

The package is the CEC Passive Solar reference model and is installed in each member country as part of the PASSYS project. Furthermore, because of its technical capabilities it is used by many of the world's leading building performance research units.

It is equally applicable to existing and new designs, with or without advanced technological features.

3D Computational Fluid Dynamics

This software has been developed specifically for the analysis of air movement and in particular, the movement of air within the buildings. This system is capable of simulating the three dimensional airflow patterns within a building or the external environment. It can be applied for the evaluation of flow regimes in existing buildings or in assessing new designs.

Lighting Simulation

Lighting can obviously have a major impact on internal temperatures, occupant health and comfort, visual appearance and vegetation survivability. Lighting simulation software is available for daylight and artificial lighting purposes, not only for lighting engineering but visualising the building interior and exterior.

Visualisation

The ASL visualisation software permits a 3D model to be created either from drawings or from data transferred directly from most CAD systems. Facilities exist for developing 3D and 2 1/2D CAD models into a full 3D format.

A variety of presentations of the final model may be produced:

- still images of the building and site in slide or print format
- photomontage material can be produced in which computer generated images are superimposed onto photographs of the undeveloped site
- smooth animation based upon any user defined path. It may be recorded onto video tape and, with the addition of commentary and music, developed into an effective corporate presentation tool for marketing and PR work.

All these simulation tools are currently used as stand alone software packages.

The ASL and Intergraph software which form the backbone of the prototype BIDS system have been identified. The principal categories are:

- Visualisation/3D Modelling
- Architectural
- Environmental/Building Services
- Civil - Site
- Civil - Structural

By comparing the available software with the requirements of the BIDS system will identify the new software to be developed or obtained from third parties.

SUMMARY

To date the success of a building design is judged after it is built and occupied. However, simulation tools are available for evaluating the performance of the building prior to construction. The use of these tools within an Intelligent Building Design System is necessary to gain full effective advantage from modern technologies. The BIDS system provides integrated information on the performance of the design from which the design team can make more considered decisions. BIDS is a design tool supplementing and complementing the designers intuitive feel for the design.

The BIDS system is applicable equally for use in refurbished design, new traditional design and more sophisticated design. The design team members each use only those elements associated with their role in the team. However, they communicate with the whole BIDS building model.

The BIDS system serves the 'building' during its life cycle: initially it helps integrate the design team decisions and more rapidly commission the building. It thereafter assists the owner during the life of the building, to maintain, operate and renovate the building.