THE ROLE OF CAD IN ENVIRONMENTAL BUILDING SCIENCE

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Abstract. The fundamental requirement of all building design is the provision of shelter from the external climate and, if possible, the modification of environmental factors generated by this climate to create an internal environment suitable for human comfort. The environmental design strategies of modifying climate derive from the requirements of creating human comfort in buildings, using the elements of the natural climate which vary throughout the year depending upon the prevailing climatic conditions. Environmental Building Science (EBS) research and practice has investigated various techniques to increase architects' performance in environmental building design. These technical design options are also available to architects to take advantage of the external environment. Most environmental design techniques rely on convectional forms of passive environmental design, and building material and system. But it hardly begins to address the more complex demands of environmental building design issues in the buildings. Particularly, testing environmental design techniques against physical models requires much input data which is not available in the early design stages, and is time consuming to use. This forces architects to work with many design parameters that are not compatible with their activities. It is consequently difficult to observe the interrelation of design techniques with design development. The most important role of Computer Aided Design (CAD) is to integrate wider varieties of input data requirements, modelling with EBS properties, output representations with EBS knowledge and assistance tools for optimisation tasks in environmental design issues.

1. Introduction

Environmental building design, climate sensitive building design or green building design, are all concerned with designing buildings that reduce energy consumption, environmental impact, and increase comfort levels. of passive environmental design, and building materials and systems. The new generation of buildings does not depend upon sophisticated equipment and high technology, but instead relies on convectional forms of environmental design, together with energy efficient and sustainable building material and system. Environmental Building Science (EBS) research and practice has investigated various techniques to increase architects' performance in environmental building design.

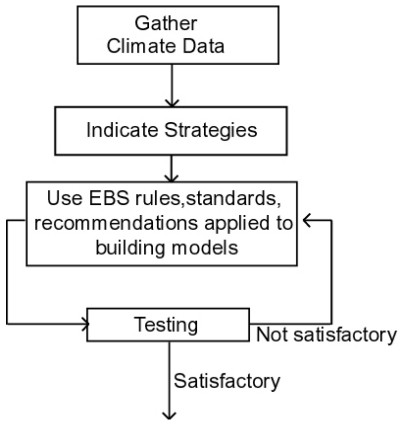

Figure 1. General EBS design process.

Fig 1 shows a simple EBS design criteria. Gathering climate data is often the first step in defining EBS design strategies. The principles of EBS design strategies derive from the requirements for creating human comfort in buildings, using the effects of the climate upon heating and cooling requirements. Many basic design techniques encourage architects to start designing by following guidelines (rules) and recommendation practices (building standards). In the case of validating EBS design techniques with building elements, the testing of buildings are required e.g. assessment, mathematical calculation or simulation. Ideally, optimal EBS design focuses on whole-building integration to achieve the best performance at minimum energy consumption. This optimisation is a variable necessary for creative design based on EBS analysis. The way EBS achieves this is by bringing ideas and techniques of EBS design together, and by developing this integration through high-level techniques of CAD modelling of design representations.

2. Functional Requirements in EBS design

2.1 EBS DESIGN AND THE DESIGN PROCESS

In the early conceptual stages of design, architects are likely to work with key building elements and functions. At later stages, once the basic design has been stabilised, the emphasis is on complete and consistent documentation, detailed analysis of performance and cost, and probably coordination of the work of many specialists (Mitchell, 1996).

Different architects inevitably choose to use different environmental strategies depending upon their own design approach or emphasis. The strategies themselves are invariably based upon design rules, standards and recommendations. Architects have to design buildings following these fundamental principles by using these contexts of rules, etc. Solar design techniques, for example, require many input parameters such as amount of solar radiation, sun's changing position throughout the year, etc. Direct gain, solar collectors and sunspace techniques are also well understood in solar design rules, but it is difficult to commence with such complex and specialised demands in architectural design (Hawkes, 1996). The source of obtaining climate data is also not straightforward in scope for the architectural design process. Early-stage architectural design is far more general than this. Night-time ventilation strategies describe advantages of the climate outside buildings, and also relate to thermal mass strategies. It is almost always the case that it is only ever possible to satisfy one of these strategies well. Consequently, EBS design solutions should seek an equally balanced solution to all of the environmental problems.

In Fig. 1, the process of EBS design in which a wide range of environmental data needs to be analysed and taken into consideration is highly complex. Additionally, there is a significant amount of uncertainty in EBS analysis. Uncertainty is introduced into the analysis in these principal areas:

- The validity of specific of EBS design strategies in the design process.
- The validity of specific of EBS techniques.
- The predictive abilities of both EBS design strategies and techniques.

The essential role of a successful design tool is to automate as many of the tedious tasks of EBS requirements as possible. The requirements require a very flexible design process, capable of satisfying the following:

- Reducing the number of parametric iteration design variables a designer may need to explore.
- Testing the viability of EBS knowledge and comparison of multiple options.

- Developing strategies that advance toward more detailed design as much as possible.
- Generating multiple building models to present the full range of ideas of architects' knowledge.

2.2 EBS DESIGN AND INTEGRATION

In any design process, the challenge of EBS tools is not only to complete all data and EBS knowledge, but also to systematically arrange all the necessary data through design development. The energy performance of each significant building element is integrated into a whole system to achieve the best building performance. The source of complexity of EBS knowledge lies in the vast amount of information necessary to adequately describe the expected interaction of software with its environment. This will incorporate existing EBS knowledge and will require numerous intermediate steps in putting it together. This process is reliable only when the behaviour and interface of integrated pieces are well understood. Building one wall adds a great deal of data to the system.

Energy saving is achieved both directly and indirectly through economic cooling, heating and lighting strategies. Green building is concerned with pollution and environmental impact, and designers are required to consider life-cycle costs. Because buildings need to be designed through a combination of strategies for balancing environments throughout the year, all EBS data requirements need to be integrated diversely.

A number of major integrations are required:

- Integration between EBS criteria (e.g. lighting, thermal and ventilation).
- Integration between architectural elements and EBS properties (e.g. U-value, surface reflectance and thermal conductivity).
- Integration between weather data requirements.
- Integration between rules, building standards and recommendations.
- Integration with other CAD modelling and EBS tools.

The above requirements not only play a role in improving designers' performance during the design process, but also reduce the number of discrete analytical software components that designers need to use and to be familiar with.

Conventional CAD systems have provided simple graphic information relating to dimensions, areas and volumes of building space. Thus, if the data integration can be made sufficiently simple and intuitive, inputting the geometry of buildings can obviate a significant amount of numeric data input as this can be derived directly by the applications when required.

The integration of EBS knowledge in the form of strategies and techniques in the design process depends on a number of pragmatic factors. These include:

- Collecting all availabilities of affordable EBS knowledge.
- Increasing efficiency and reliability of EBS knowledge.

It is most likely that the use of this integrated database structure would encourage a similarly structured design process based upon architectural knowledge of high-level design elements, definition of type/subtype relations, parametric variation, and spatial instancing (Mitchell, 1996). Consequently, the automation of the geometric selections between building elements can reduce data entry time and substantially increase model editability. In addition, the essential requirement to support cyclical design development (Szalapaj, 2001) in optimal cases are required to refine each EBS technique to achieve the most comfortable indoor climate.

2.3 EBS DESIGN AND REPRESENTATION

Mahdavi (Mahdavi, 1993) claimed that the representation of simulation environments should not only be completed with terms and rules of design and performance variables but also indicate users' goals, expectations, interests, intentions and views. Direct gain, sunspace and solar collector systems are daylight techniques to increase heat gain to building. These techniques are difficult to relate to how architects can start to design buildings. The representation of EBS techniques suggests a need for elaboration on the representation beyond the level of apparent entities such as space and building elements.

Indeed, the convergence of architectural design and EBS design is a graphical representation requirement. The data for input, manipulation and results, for example, should be presented in an understandable way, preferably graphically. Outputs of the environmental programme should not prevent architects from quickly evaluating their designs by producing excessively detailed and hence incomprehensible results. This requirement should focus on the graphical presentation of EBS knowledge instead of numerical representation. One way of achieving that is to treat EBS data not as integral entities, but as a container of other intermediate elements.

'Models developed for different design tasks therefore omit different kinds of details. Building a model that is adequate for more than one task requires a clear articulation of demand that each task places upon the model' (Szalapaj, 2001).

Most EBS design is concentrated on precise object performance and function. As a result, EBS models often present a low level of graphical detail rather than a high level of visualisation. In some cases such as lighting analysis, however, the result of colour is more important than other results.

The problem with this approach is that there are far too many variables, which all interact in non-linear and complex ways. Performances depend not only on the strategy and implementation, but also on climate, building use and the local context (such as occupancy pattern). The main ideas of EBS design can be inferred from the context in which an object is created or, more importantly, from the group of actions that may have preceded it. Similarly, it is possible to provide a number of alternate means of invoking the same action, each with different consequences for associated data. This subtask becomes the guide for designing parts of user interfaces.

Three major requirements for appropriate representation for architects' activities are:

- Making input parameters and output representations compatible with their intended activities.
- Making architectural models represent EBS data intuitively and clearly.
- Arranging all available EBS knowledge into particular design contexts.

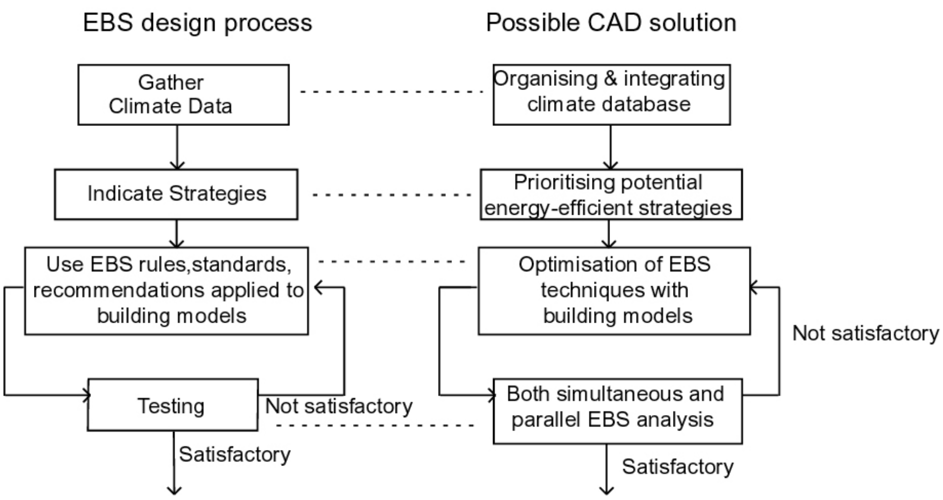

Figure 2. The requirements of CAD functionality in an EBS design process.

One promising approach to these essential difficulties is to rigorously deal with the problem of gathering and specifying requirements through EBS design criteria. Fig. 2 shows the principle CAD functional requirements in each step of the EBS design process.

3. The Specification

The specification generally refers to a statement of particulars describing the structural and behavioural details of the product to be developed (Alagar, 1998). EBS system specification denotes a precise description of system objects, a set of methods to manipulate them, and a statement on their collective behaviour for the duration of their existence in the system to be developed. The specification requirement produces a more precise definition of EBS system attributes. EBS descriptions, properties, and operations must be dealt with as a whole for sensitive building objects in the system during their entire evolution. Specification may be regarded as a multistage activity rather than a linear one. The following are specifications of an EBS system which covers the complete range of environmental requirements in the architectural design process.

3.1 INPUT REQUIREMENTS

Input requirements are concerned with managing, representing and integrating the number of iteration design variables an architect may need to explore. The most critical input requirements that need to be considered in an EBS system are:

- Determining whether specific parameters have significant effects on design strategy responses to the building design.
- focusing on specific parameters that are directly influenced by the architectural design process.

3.1.1 Climate Data

Climate data requirements in EBS design depend on the methods and details of EBS analysis. Fig. 3, in early stage design processes, some climate data, such as monthly range of temperature and humidity, can produce fundamental design principles based on designing the crucial features of buildings such as their orientation, for example. In later stages of combination of more strategies, hour-by-hour climate data is required, because these involve many variables which are integrated to equally balance solutions of all selected EBS techniques.

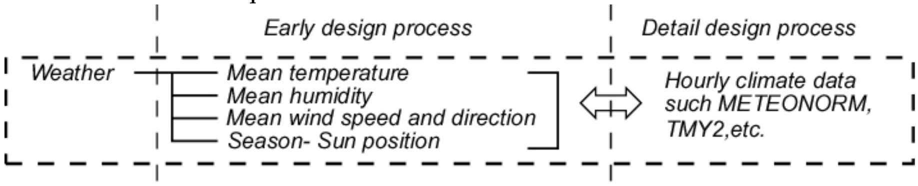

Figure 3. Interrelationship between requirement data in the design process and requirements of climate data in the system.

As a result, climate data requires lots of intermediate steps in putting them together to suit the design process. All climate information needed to describe an environment for analysis should be integrated. Climate data for EBS system design and analysis should be available in certain functions:

- Suitable amount of climate data for each design stage in terms of presentation and interaction.
- The system should allow designers to integrate existing climate data applications.

3.1.2 Building the Model and EBS properties

EBS information within architectural design should be represented in terms of visual models rather than as numerical ones, since it is not only necessary to carry out precise analytical functions, but also to assess the quality of the design presentation. Ideally, when creating the model object, it should be associated with EBS information. Figs. 4 and 5 show how object elements might be integrated with EBS information. However, EBS parameters need to be organised before being applied to the object.

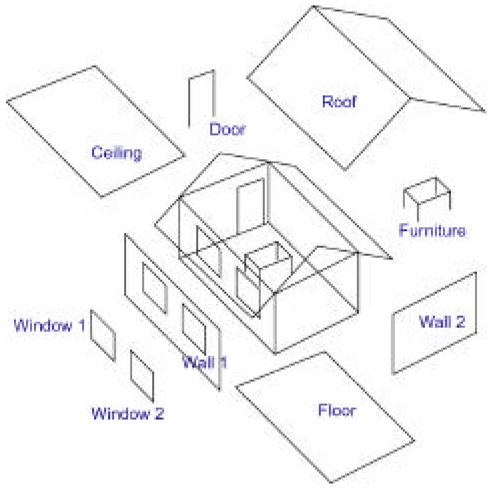

Figure 4. A simple building elements hierarchy for EBS design.

Default values provide information which can be inferred from the context in which an object is created. It is possible to provide a number of alternate means of invoking the same action, each with different consequences for associated data. In fig. 5 default values of a wall, users need only select on a wall type in order to enter the initial value. Building types such as schools or high capacity offices or low light offices can be described with a completely

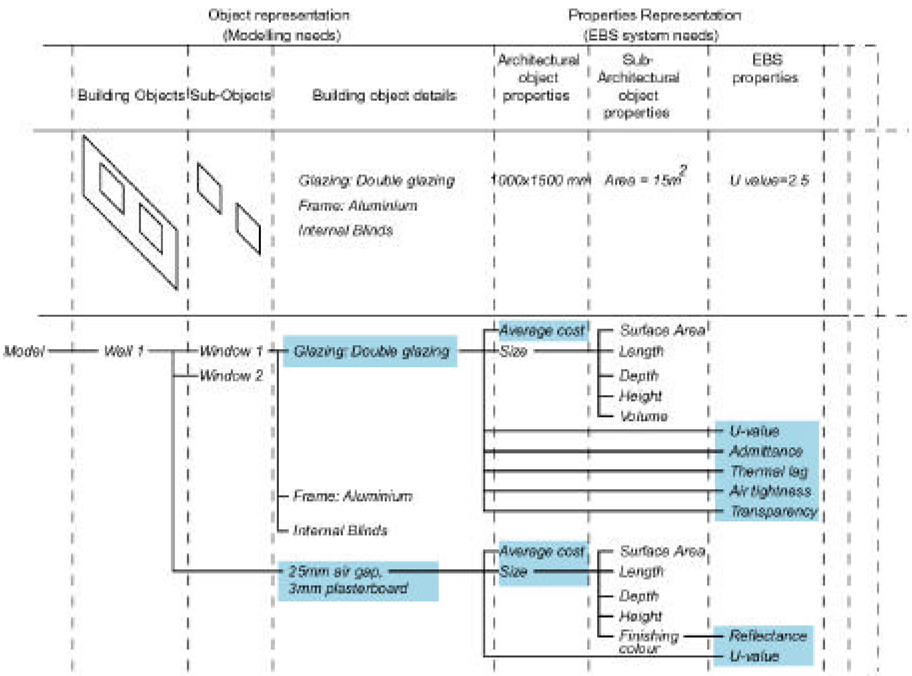

Figure 5. Hierarchy of building material default values.

different set of default data. These are examples of typical or standard building types. It is also important in an EBS approach, that it should be possible for designers (users of the system) to describe their own default values for non-standard or atypical building types.

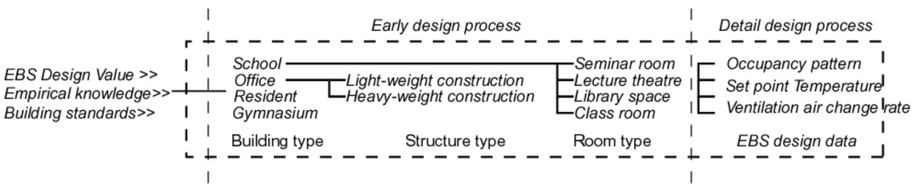

Figure 6. Automating default values of EBS data with database of recommendations and building standards.

Default data can help architects to reduce the amount of data input (Fig. 6). In the early design phases, designers concentrate on building form and main building elements. This is helpful in terms of automating detail data with databases of recommendations and building standards. Once the main design idea has been stabilised, further emphasis can be placed on material details and properties, and maintaining their consistency. Default values can be set up later as design recommendations for specific types of objects. Typical schools or academic buildings can be described in terms one single default data set for a whole building. This then allows designers to focus more on detailed description of building function. Default descriptions can be used for building spaces such as academic staff rooms, classrooms, lecture theatres and tutorial rooms.

Default values can be obtained from prototype databases, based on building locations and building types and in some cases space types and boundary types. The rules for the selection of default values follow from building codes, standards and recommended practices, taken from a number of sources such as the BRE code of practice.

3.2 EDITABILITY AND MODELLING

Optimisation of EBS techniques is required for making balances between combinations of these techniques. Models need to capture the variety of architectural design styles and approaches that relate to environmental emphasises and preferences. The content model represents a design practice's own contents and organisation. Using all the knowledge built from creating, refining interacting with task cases, and grouping parameters into categories on the basis of how strong they seem to be related, this will influence how likely users in any one practice will effectively and efficiently perform tasks together. Editability and modelling are therefore essential processes for optimisation of EBS techniques.

3.2.1 Climate data manipulation

Climate data manipulation is concerned with determining one of the potential benefits of EBS strategy. In early stage design processes, producing the most useful building strategy is important, and should basically be the starting point of every EBS design. The system should allow the identification of strategies quickly, and the categorisation of strategies according to their effectiveness. A further property of EBS techniques is to allow optimisation of the effects of a number of building elements. Fig. 7 indicates the modification of design descriptions to respond to energy-efficient strategies in the design process e.g. selecting strategy to suit climate, and producing fundamental design strategies and recommendations for the crucial parts of building elements.

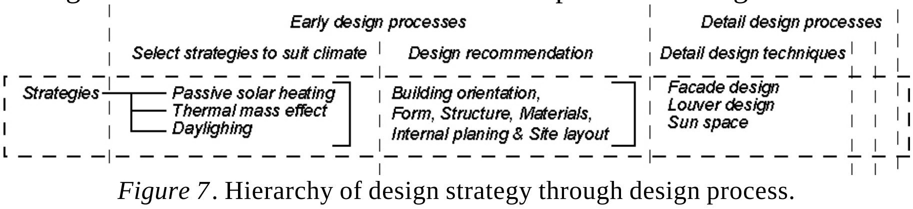

Figure 7. Hierarchy of design strategy through design process.

3.2.2 Model manipulation associated with EBS properties

As it is a requirement for designers to freely access, modify and observe the relevant variables of different design techniques, design tools should facilitate the interactive and simultaneous modification of properties and the observation of change in various contexts, designs and performance variables. Tools need to be provided for precise manipulation associated with EBS techniques in design development. Model manipulations concern two main areas of information:

- Architectural design knowledge.
- EBS knowledge

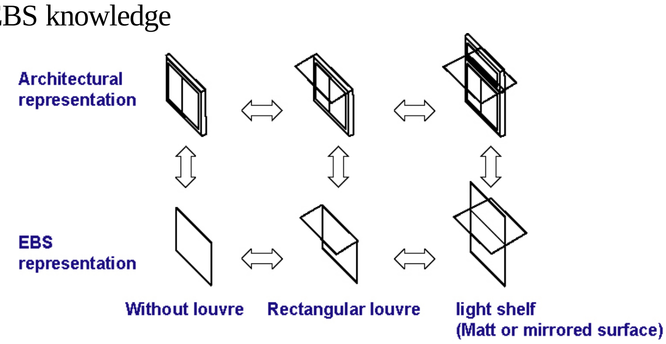

Figure 8. Interrelated modelling between architectural and EBS design.

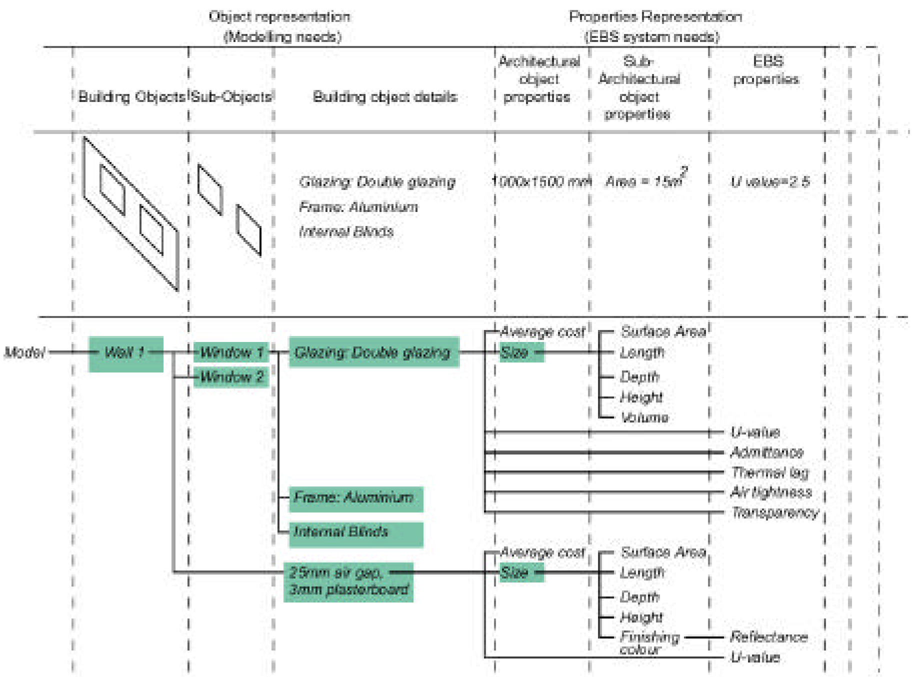

Figure 9. Areas of priority for model manipulation.

In fig. 8, 3D models need to represent main architectural ideas such as these associated with visualisation. While EBS design needs to be integrated with environmental design knowledge, conventional CAD systems provide many separations of architectural context. If EBS information keeps hierarchies of default data, materials and their properties, then the possibilities of user-manipulation and re-definition improve. Fig. 9 illustrates the priority objects which architects may modify and thus the change set of building properties.

4. Conclusion

Designing buildings with EBS knowledge should largely be influenced by design decisions made by architects during the design process. It consequently has a major role to play in the design of energy efficient and comfortable buildings. Unfortunately, architects rarely consider applying EBS knowledge to their design. To overcome this difficulty, the role of CAD in EBS design should be:

- To represent and allow the modification of objects that integrate information between architectural design and EBS design in one single model.
- To represent and support objects that communicate information between EBS knowledge specialisms (e.g. energy and lighting, for example) and pass it between these specialised modules.

Input of design information in EBS systems mean the identification of relevant objects, aspects, parts and properties of these objects, as well as relationships between objects. Such information is normally not explicit in conventional CAD software or other digital design documents. Object-based modelling based on default values offers promising support for flexible and efficient manipulation throughout the design process. EBS design brings together all the information needed for non-linear activities, which should encourage architects to improve their design performance.

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