Building Codes and Performance Standards as Knowledge-Bases for Design

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Abstract

Code compliance checking is an integral part of the building design process. Many research attempts have been made to automate code compliance checking as a secondary task to developing a design solution. But it is possible to represent the code requirements in a knowledge base to assist in the design process. In the present study, a building envelope design knowledge base has been developed to model the performance based design approach. The National Building Code of Canada's design requirements and an ASHRAE standard specifications for building envelope are incorporated in a knowledge base. A frame-based knowledge representation technique is used to implement the semantic relationships among the design context attributes. Once the performance attributes are established in the design context, then design alternatives can be generated. A database of standard construction types for walls, roofs and glazings is developed to contain the material properties data required to generate design alternatives. This paper presents the knowledge acquisition and representation of building code and performance standards information, and also briefly describe the design process implemented in a prototype system.

Introduction

There is a need to develop models and tools for early design stages because of the high impact of early design decisions on the building quality and performance [BRB 85]. Selection of materials and construction types are among the most important decisions made during the preliminary design stage. Building envelope design process requires many different types of information for establishing the design context and in generating the design alternatives. During the preliminary design stage, very little information regarding the building such as its location, geometry, type of occupancy and budget are available. The definition of quantitative performance requirements at this stage depends on the experience and knowledge of the designer to make appropriate assumptions.

The knowledge base applicable to a particular building or product is seldom found in a single publication, and is more likely to comprise materials published in text books, design guides, data bases, building codes and performance standards. In the case of building envelope design, it is possible develop a database of material properties and construction types, and integrate this with a knowledge base of design heuristics and performance standards. This approach is implemented in a prototype building envelope design system known as BEADS. The present study considers performance attributes relating to thermal resistance, moisture protection, cost, material compatibilities and thickness requirements. Some of these requirements can be established as target values in the design context whereas others can be determined only during the design alternative generation process. For example, the check for interstitial condensation and material compatibilities can be

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performed during the alternative generation process, hence they may be represented as procedures and part of the material properties respectively.

Weather Data

Design weather data including degree days, summer and winter design temperatures are needed to establish the thermal performance requirements of envelope components. The supplement to the National Building Code of Canada [NBCC 85] provides data tables from which design weather data can be retrieved simply by knowing the building location. A schema "CITY-NAMES" is defined to consist of slots corresponding to city names. Instances of this schema are used to represent the various design weather data items such as design degree days and design temperatures. Knowledge representation of weather data using this technique offers many advantages for incremental development, easy updating and retrieval. There are about 80 major locations in Canada currently available in the prototype system. More locations can be added to the "CITY-NAMES" schema by creating new slots which will be inherited by the related schemas representing the weather data. The addition of more environmental data specific to a location such as wind pressures and ground snow load can be done by defining new schemas and relating them to the "CITY-NAMES" schema. Then the corresponding values can be specified for each location.

If the designer specifies the location of building, then all the weather data required for establishing the design context can be retrieved. This approach reduces the amount of user input and at the same time offers the facility to examine the influence of location on the outcome of design.

Energy efficiency requirements

Building envelope contributes significantly to the amount of energy consumed by the space heating and cooling systems ([AIA 82], [Guide 82]). The need for energy efficient design of envelope components has long been recognized and regulatory authorities have developed standards for the optimum use of energy. ASHRAE Standard 90A-1980 [ASHRAE 90] for energy conservation in the design of new buildings provides the minimum thermal performance requirements for the envelope components. The intent of this standard is to be flexible in order that designers be encouraged to use innovative approaches and techniques to achieve effective utilization of energy. This standard covers new buildings that provide facilities of shelter for public assembly, educational, business, mercantile, institutional and residential occupancies as well as portions of warehouse, factory and industrial occupancy which are primarily used for human occupancy.

Guidelines and graphs are provided by this standard to determine the overall thermal transmittance (U_o values) for the envelope components. The type of building and degree days of location can be used to find the U_o values for gross area of walls and roof. Empirical relation such as the following equation can be used to meet the overall heat loss requirements ([Goodwin], [Analysis 82]).

$$U_o^* = \frac{U_{wall} * A_{wall} + U_{fenestration} * A_{fenestration} + U_{roof} * A_{roof}}{A_{wall} + A_{fenestration} + A_{roof}}$$

The U_o values of walls and roof provided by the standard are meant for the gross area of envelope, whereas it is seldom possible to meet this U_o requirement for windows, doors and skylights. Hence area averaging technique using the above equation allows trade-off to examine different combinations of envelope components. For example, the individual U_O requirements for wall and roof can be relatively increased or lowered beyond the minimum requirements specified by the standard, but the combination must satisfy the overall U_O^* requirement.

The wall and roof U_O values, the overall thermal transmittance value (OTTV) and solar factor are obtained from the ASHRAE standard and defined in the design context as performance requirements. The U_O values and the gross area of envelope components are then used to establish an energy budget. During the alternative generation process, the heat loss for each combination of envelope components will be calculated and checked against this energy budget. In addition, multistorey buildings belonging to category (iv) will be checked for cooling requirements using OTTV-wall values as specified in clause 4.4.3 of the ASHRAE standard.

The ASHRAE graphs to determine the above values can be represented in many different ways. These graphs typically require the building type and degree days of the location to determine the overall thermal transmittance values. Production rules or procedures can be used for representing the ASHRAE requirements. The present implementation uses LISP functions and the graphs are represented in procedural form. These functions are accessed by the design context after knowing the user input on building type and location, and return the appropriate Uo value depending on the degree days. Though production rules can also be used for this purpose, they are not efficient when a large number of such graphs are required for one particular performance attribute. In a schema/frame-based implementation, it is easier to represent them as procedural attachments known as demons. The following section presents an example of "DESIGN-CONTEXT" schema and describes how demons are used in establishing the performance requirements.

Example

The design context consists of user requirements and performance requirements as constraints to define the boundary of admissible design solutions. Figure 1 shows an example of "DESIGN CONTEXT" schema, its slots representing the design parameters, the source of information and the relationship between them. User input of building location is used to retrieve weather data corresponding to degree days and design temperatures and latitude. The building type and degree days information are used to establish the U_O for wall and roof in the slots "UO-WALL-HEATING" and "UO-ROOF" respectively. Once these U_O values are known, an energy budget (specifying the allowable heat loss through the envelope) can be established by multiplying the gross envelope area of components and the corresponding U_O requirements. If the building type is 4, then "OTTV-WALL" and "SOLAR-FACTOR" values are obtained from the ASHRAE 90A-1980 graphs to check the energy requirements for cooling season. These values are dependent on design latitude and are currently represented in demon functions written in common LISP.

The relationship between performance attributes are dynamic in nature for maintaining the consistency of the design context information and the logical dependency of performance requirements. For example, when the value of energy budget is requested during the generation process, a demon is executed to operate on the U_O values and area of envelope components. The request for U_O values in turn invokes a demon to calculate this value which depends on degree days. The data retrieval for degree days in turn executes a demon which uses the location name. Thus modifying any user input parameter such as building

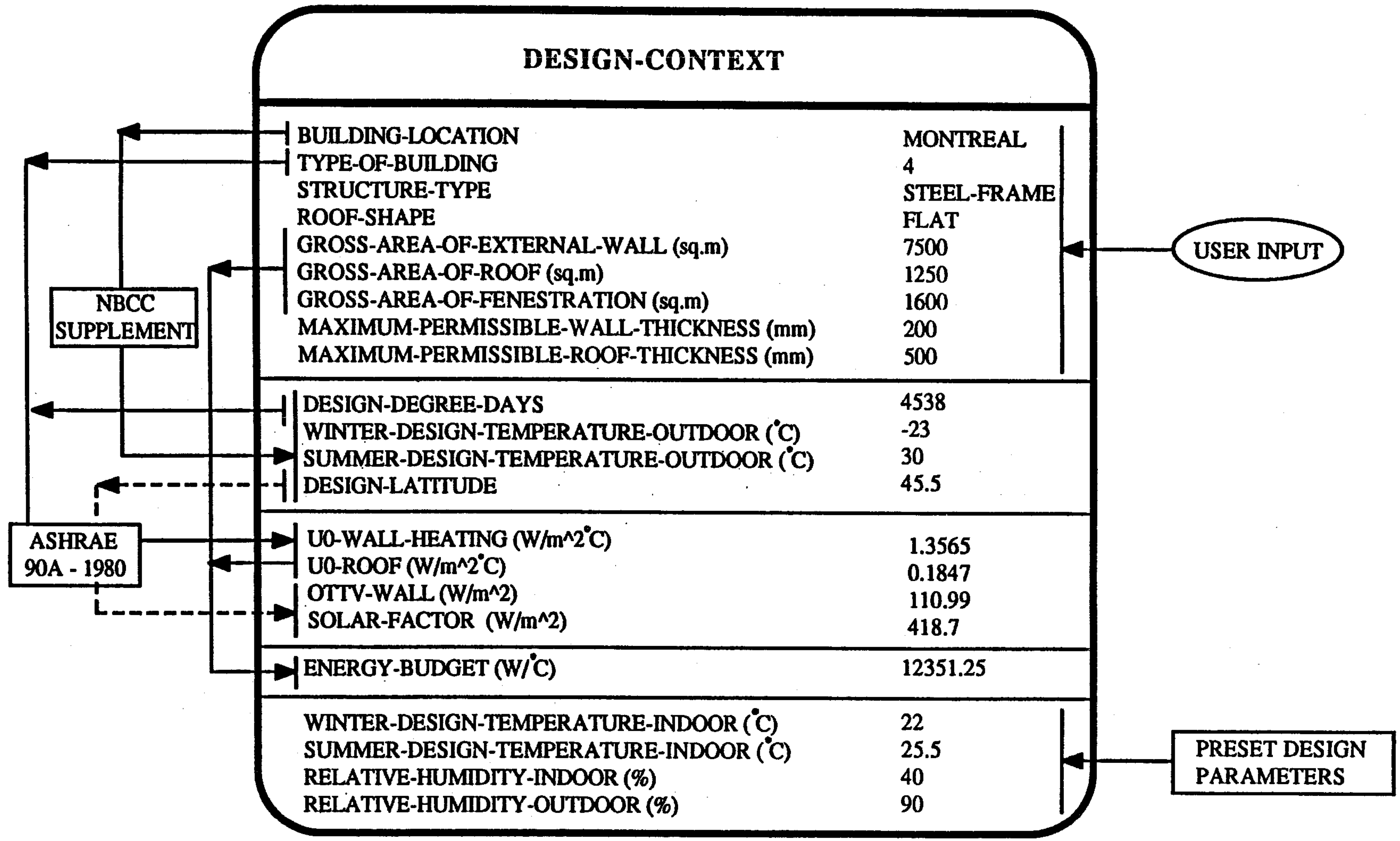

Figure 1: Example of a Design Context and Information Sources

location or envelope area will automatically reassert all the performance requirements which are dependent on them.

The structure type and roof shape information are obtained as user input and used in the alternative generation to check the compatibility between systems and materials. In addition, the preset design parameters on indoor design temperatures and relative humidities are used in a condensation check for finding potential problems in wall systems as they are generated. Thus most of the performance related constraints established by the design context are used in the alternative generation process to check suitability of materials, systems and their combinations.

Design Alternative Generation Process

The generation of design alternatives is viewed as a constraint-based search process in which constraint satisfaction is checked at three different levels, namely: material, component and system levels. Constraints for the alternative generation process are defined by user and performance requirements, functional relationships between materials and components, and design heuristics. At the material level, only material compatibility constraints are considered. But at the component and system levels many other constraints are checked. These checks may be simple predicate relationships or more complicated analytical computations and verifications. In the BEADS prototype implementation, the following constraints are considered:

(i) Compatibility of structure type for wall and roof

(ii) Compatibility of building type for wall, roof and fenestration

(iii) Permissible thickness of wall

(iv) Minimum R-value requirement for wall assembly

(v) Static condensation check for wall assembly

(vi) Compatibility between roof shape and roof type

(vii) Permissible thickness of roof

(viii) Energy consumption of the envelope

(ix) Cooling check for wall assembly, if required

(x) Compatibility of materials

The generation of design alternatives begins with the selection of a basic wall type which is suitable for the user specified structure type, building type and maximum permissible thickness. If this basic wall type requires a structural framing, then an appropriate structural material is identified and the basic wall description is redefined. Once such a basic wall type is identified, the available wall insulation materials and their thicknesses are considered one after the other to meet the thickness requirement and total thermal resistance of the wall assembly including the insulation. Now this wall assembly is checked for possibility of interstitial condensation. A simple static condensation analysis (considering only moisture diffusion) is carried out by knowing the thermal and vapour resistance of each layer, the indoor and outdoor design temperatures and relative humidities. Thermal and vapour pressure profiles are established to determine the location of dew point. If the dew point lies in the wall cross section, then this alternative is eliminated.

In selecting the basic roof type once again the constraints on suitability of structure type and building type, and the permissible roof thickness are applied. In selecting roof insulations, material compatibility is also ensured. Now the wall and roof assembly are combined with a suitable glazing type to form an envelope assembly. Energy consumption reflecting the heat loss through the present combination of envelope components is calculated by multiplying thermal transmittance and surface area for wall, roof and fenestration. This value is checked against the energy budget established by the design context. If the building requires a cooling check (according to ASHRAE standard 90A-80), then this is also carried out. If all these checks are successful in meeting the requirements, then this combination of envelope components is specified in an instance of feasible alternative description. Such instances are created at run time and consist of slots to represent the basic wall type, wall insulation, basic roof type, roof insulation, glazing type, thicknesses of walls, roof and insulations, and the performance attributes and utility values required for ranking the alternatives. The energy consumption, total thickness of wall and roof are values of constraints evaluated during the generation process.

The above process of alternative generation is repeated until all feasible combination of envelope components are identified. At each instant of constraint violation, the alternative generator back tracks to the previous level. For example, if the condensation check for a wall assembly fails, then other available thicknesses of the insulation material are tried until a successful one is found. If there are no suitable thicknesses in this insulation material, then another wall insulation material is chosen and the process is continued. On the other hand, if there are no other wall insulations available, then a different basic wall type is considered and the subsequent checks are made. This process follows a top-down search process for generating all feasible combinations of components and materials by satisfying constraints at various levels.

Ranking and Selection of Alternatives

The alternative generation process results in the identification of all feasible combinations of envelope components which meet the user and performance requirements specified by the design context. These feasible alternatives must be ranked in a systematic fashion for enabling the designer to select the most suitable solution.

The BEADS system has a two stage selection process. The first one allows the designer to specify the preferred construction types for wall and roof, and the second stage lets the designer specify priorities of performance attributes. The preferred feasible alternatives are ranked on a percentile scale for each performance attribute and the priorities on performance attributes are used to compute the overall utility value for the alternatives. This approach provides a simple, yet meaningful scheme for decision-making at the preliminary design stage, since it relies on the best relative performance of a given alternative within a set of feasible ones. The performance corresponding to each selection attribute of all feasible alternatives are determined at the time of generation. The performance data for each attribute has a different unit and needs to be normalized for ranking purposes. In order to address this issue, utility values based on a percentile scale can be established.

An additive utility criteria is then used to consolidate the utility values of all performance attributes, thus establishing an overall utility value for each alternative. At this time, it is possible to accommodate the designer priorities on performance attributes. These priorities can be treated as weights with which the utility values can be scaled. The alternative with the highest overall utility value is suggested as the most suitable solution. A more detailed description of the BEADS design strategy, knowledge representation and implementation is reported in Gowri [Gowri 90].

Conclusion

Representation of building code and performance standard information in a knowledge-based design environment simplifies the design process by incorporating compliance checking as an integral part of decision making. This approach enables designers to concentrate on the more creative aspects of design and provides the ability to examine several design alternatives. The BEADS prototype knowledge representation and implementation strategies demonstrate the feasibility and practicality of the knowledge-based design tools. Further work at the Centre for Building Studies is undertaken to revise the BEADS knowledge base for ASHRAE 90.1 Standard. Case-based reasoning techniques are also being developed to incorporate learning and automatic updating of the knowledge base.

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