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NIRMANI : AN INTEGRATED CASE-BASED SYSTEM FOR STRATEGIC DESIGN AND ESTIMATING

Srinath, Perera

Department of Building Economics, University of Moratuwa, Moratuwa, Sri Lanka. (Home University)

(Current Address: Department of Surveying, University of Salford, Salford M5 4WT, UK.)

e-mail : R.S.Perera@Surveying.Salford.ac.uk

Ian Watson

AI-CBR, University of Salford, Salford M5 4WT, UK.

e-mail : ian@ai-cbr.org

Abstract

NIRMANI (meaning "Creator" in Sinhalese) is an integrated case-based design and estimating system developed for the construction industry. It uses a multimedia case base of previous designs (which enables visualisation of designs plus the end product) and their corresponding cost analyses to develop new design and the corresponding cost plans (initial estimates) for future design development. The adaptation process is interactive for the most part with the system providing knowledge guided assistance for Design & Cost adaptation where appropriate. This paper briefly identifies the need for integration of design and estimating and introduces CBR as an ideal cognitive model for case-based design & estimating and explains in detail the case memory organisation structure, retrieval and adaptation of cases. This paper also includes a critical comparison of the NIRMANI system with other comparable CBD systems in the domain of building design.

KEYWORDS : **Case-Based Design, Computer Aided Design, Integrated Design, Cost Estimating, Multimedia.**

1. Introduction

The Construction industry is fragmented by nature. The design process is separated from the construction process and the essential involvement of numerous design, estimating and construction professionals exacerbates fragmentation (Hillebrandt, 1984, 1985 ; Raftery, 1992). In the past, researchers have used IT for providing numerous decision support systems for the professionals involved in the industry. These have created “islands of automation” and are far from achieving an acceptable level of integration across disciplines and across the design and construction processes (Kartam, 1994). For example, ELSIE (Brandon et.al., 1988) a noteworthy successful Expert System (ES) in the domain of early cost advice, provides advice on initial project planning, procurement system selection and investment with the absence of design. Therefore, it could be said that the peculiar nature of the construction industry impose unique constraints on IT systems that are developed for the industry, in comparison to other more closely integrated industries such as manufacturing.

In the manufacturing industry attempts have been made to achieve the concept of *“design to manufacture”* (Cutkosky & Tenenbaum, 1990). But in construction attempts made to achieve integration between design and construction (i.e. the concept of *design to construct*) has been faced with many difficulties (Alshawi & Underwood, 1994). For example, prototyping is rarely a solution, as building functional prototypes in construction is not economical. This leads to the possibility of using simulation instead of prototyping. But this requires a developed design. Since, 80% of cost effective design decisions are made during the early design stage (Turner, 1993) simulation becomes of less use for early stage building design. Further, the fragmentation of the industry also hinders the achievement of the concept of *design to construct*.

Instead of generating designs from first principles the mass of knowledge embedded in existing designs could be used to create new designs. It is known that architects use parts of previous design solutions in creating new designs (Pearce, Goel et.al. 1992; Hua & Faltings, 1993; Schmitt, 1993 a). Thus, previous design solutions can be used as prototypes in developing new designs. Moreover the state of the art technologies of multimedia (Maher & Balachandran, 1994) and Virtual Reality (VR) can be used in visualising and simulation of designs.

The technique of using previous designs for creating new designs is known as Case Based Design (CBD) (Schmitt 1993 a & b). This uses the Artificial Intelligence (AI) technique of Case Based Reasoning (CBR) (Kolodner, 1993 ; Watson & Marir, 1994) which organises previous design solutions as design cases in a library. The experience gained through previous designs are stored as episodes (Schank & Abelson, 1982) and is retrieved and presented to the user. Knowledge in these previous design cases needs to be organised so as to accommodate different views of the same design data space for each of the different disciplines involved in the design process (Rutherford & Maver, 1994) i.e. the design case knowledge structure should accommodate the many perspectives of the design held by the professions involved (Auoad et.al. 1993).

This paper develops a framework for a CBD system that integrates the concepts of ***“design to cost”*** and ***“design to construct”***. This is achieved within a CBD system that uses previous design cases stored with their cost structures for creation of new designs to new situations via an adaptation process. The adaptation process adapts the design, optimises the design to eliminate some construction problems and creates a cost plan for further design development. Therefore, it is anticipated that the system when fully implemented will enhance the design process.

The high level aims and the objectives of the research reviewed can be summarised as follows ;

1. Achieve integration of design, estimating and construction process.
2. Enhance the design process by reducing the design life cycle and improving inter-disciplinary communication and understanding of design.
3. Improve understanding of the client requirements by assisting to develop the design brief.
4. Achieve “best practice” through the use of previous design and construction experience.

In order to achieve these high level objectives the design process and the parallel cost planning process was examined to identify aspects that need to be addressed for integration. It was revealed that the use of previous successful design forms a viable alternative to generation of designs from first principles. It is also known that architects use pools or chunks of previous design solutions in creating new designs (Akin, 1986 ; Schmitt, 1993 a ; Pearce, Goel et.al. 1992). The following section briefly examines the philosophy behind CBR and its use in CBD.

2. Case-Based Reasoning & Case-Based Design

Case-Based Reasoning is a rich research paradigm within AI which addresses both research agendas of scientific or philosophical issues and technological or practical issues. Design is a domain where an explicit domain model does not exist or is not yet adequately understood. Thus, it is an ill-structured domain (Simon, 1973) and in the design process, design experience and heuristics play an important role (Maher, 1993).

Kolodner (1993) explains design as a process of constraint satisfaction in creating an artefact that performs a certain function or fulfils a need and in most cases constraints may be under specified. Thus, there could be many solutions to any given design problem. Sometimes all constraints may not be able to be satisfied which means a compromise is the only solution. Often these constraints cannot be considered in isolation, but their combination as well.

With CBR, the designer is offered previous solutions to a similar problem (Schmitt, 1993). The old case suggests a design itself or a partial design or design framework, to the designer. It indicates how a previous set of constraint combination was handled (Kolodner, 1993). Thus, it provides the designer at least a starting point, if not for a complete or comprehensive solution. This process of using previous designs in the creation of new designs is known as Case-Based Design (CBD). Maher (1993) describes CBD as a hybrid approach as it uses specific design cases in conjunction with some generalised or compiled knowledge.

3. The Integrated Case-Based Design & Estimating System (NIRMANI)

This paper describes a case-based approach that integrates the design and estimating functions in construction and that will achieve the aforementioned objectives.

Presently research is being carried out to implement the proposed system initially for Light Industrial Buildings LIB (eg. warehouses) and subsequently to be extended to commercial building types (eg. office buildings). The scope is limited initially for LIB for practical reasons of developing a working prototype that demonstrates the validity of the concept. Further, it enables the usage of existing rule-based ES, ELI (the ELSIE Light Industrial Buildings version) a system built at the Department of Surveying, University of Salford for generating cases for testing. It also provides the foundation for a comparative study of ES development and its comparative version of CBR system to be comparatively evaluated, as to the validity of application of CBR cognitive model in real time design and estimating processes.

The NIRMANI system (semantically described in Fig. 1) aims at generating a schematic design for LIB by retrieving previous design solutions that matches the problem specification from a multimedia case library. The retrieved design shall be adapted if required, architecturally, structurally, for services requirements, ultimately providing a cost plan for the building to form as the budgetary guide for further design development. The entire CBD process is interactive giving the designer sufficient authority to guide the design process and achieve creativity as much as possible.

The numerous stages of the case-based design and estimating process are briefly explained below.

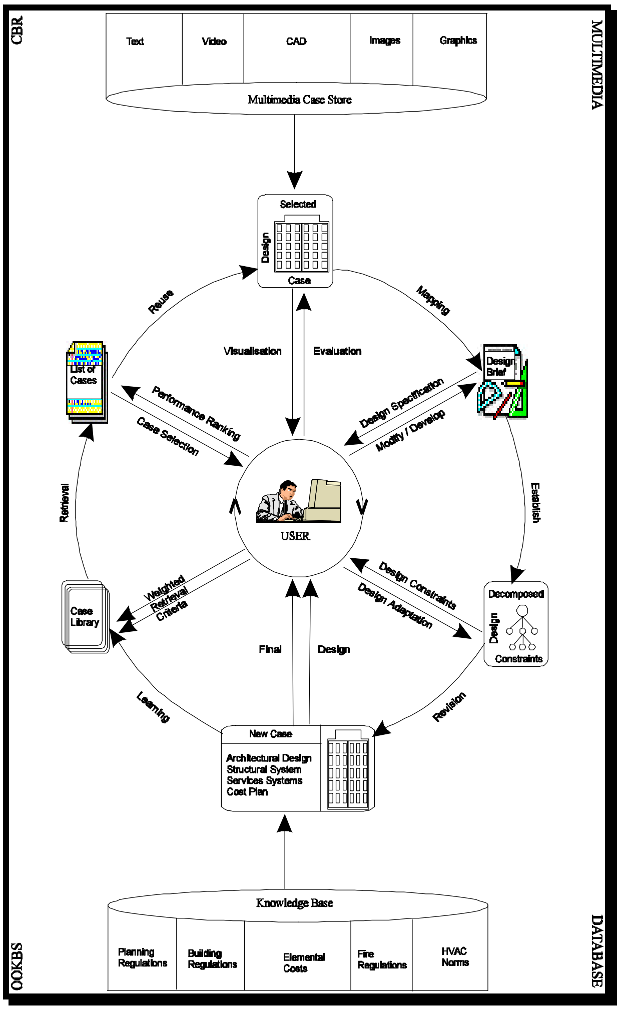

Fig. 1 CBD & Estimating Process : An Overview

1. The NIRMANI system starts a session using a vague client brief with each criterion being weighted (for example, number of occupants, total cost, shape etc.) to retrieve a set of cases ranked according to its match to retrieval criteria.
2. The multimedia case store allows the user and the client to visualise any preferred case from the list by means of 2D & 3D CAD images, video images, scanned images (photograph), text etc.
3. The user then evaluates and confirms the selection of the most preferred case.
4. The system maps all the design information to the new case creating a design brief (building specification) for the new situation, based on the original case.
5. The user can modify and develop the brief to suit his requirements.
6. The system compares the developed brief and the requirements with the original

case and establishes design constraints for each decomposed design perspective / element.

7. The system, then for the most part, uses an interactive adaptation process to satisfy design constraints and revise the design using knowledge obtained from the knowledge base in the form of methods and rules.

8. Once constraints are satisfied (to a level acceptable to the user) and the user accepts the new design, it is stored in the case library as a new experience to the system, thus completing the CBD cycle and learning from the new experience, i.e. the system conforms to the *dynamic memory model* (Schank & Abelson, 1977; Schank, 1982).

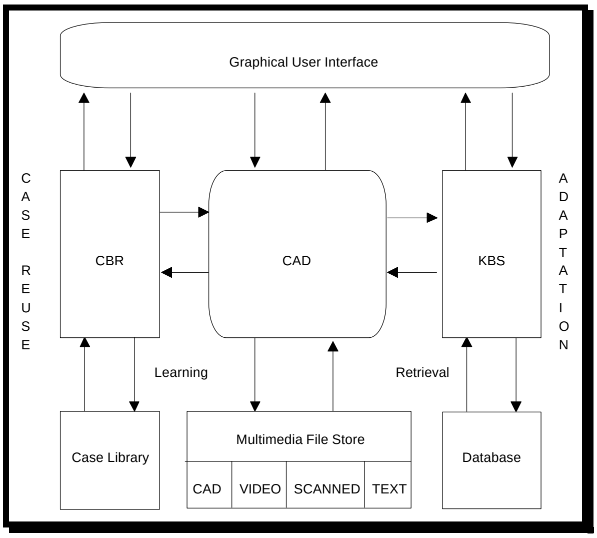

Fig. 2 Overview of System Architecture

The NIRMANI system maintains the many perspectives of the design professionals involved in the design process but avoids information storage on the perspective of the client in order to rationalise information storage and minimise redundancy. Further, at a given time the client or user may take any of the perspectives of Architect, Structural Engineers, Services Engineers & Quantity Surveyor or all of it. Fig. 2 depicts the system architecture.

4. Critical Comparison of NIRMANI

The CBD systems developed for the construction industry and found in the literature can be classified as :

1. Design Aid Systems eg: ARCHIE, ARCHIE II, MEMORABILIA
2. Design Generative Systems eg:CADSYN, ACABAS, CADRE

The NIRMANI system proposed, mostly falls into the second category with a component of knowledge guided design aiding while adaptation. Most of these systems deal with either architectural design or structural design. Only ACABAS approaches both structural and architectural design. The NIRMANI system deals with architectural schematic design, structural grid optimisation, services system selection and cost planning. Thus, attempts at giving a comprehensive design.

In terms of design re-use, CADRE (Hua et.al. 1993) and ACABAS (Schmitt, 1993 a & b) use a manual case selection procedure whereas ARCHIE (Goel et.al. 1991) & MEMORABILIA (Oxman, 1993 a & b) selects matching cases to provide guidance to the designer but not for direct re-use. Only SEED (Flemming et.al. 1994 a & b), a system at the conceptual stage, proposes a complete re-use of design for design generation. But it is more of a design generative system using first principles of design with a component of case-based reasoning to assist the design generation task. On the other hand, the proposed system provides automatic retrieval of the most appropriate case directly for adaptation and/or re-use.

Unlike most CBD systems developed, NIRMANI is envisaged to learn by itself, acquiring new cases it generates thereby maturing with experience along with the user or the architectural firm, using the system. This puts the system in line with SEED but clearly distinguishing from other approaches that rely on considerable efforts to build a memory of cases (Rosenman et.al. 1991 ; Domeshek et.al. 1992 ; Hua et.al. 1992 ; Schmitt 1993 a & b, 1994). But SEED uses a combination of space generation Expert Systems [LOOS, ABLOOS & GENESIS (Flemming et.al. 1989, Coyne et.al. 1990, Heisserman et.al. 1993) to develop the design and case-based support is provided where available. Further, case indexing will be hidden from the user thus providing greater enhancement in usability.

It is intended that case adaptation to be semi-automatic allowing a certain degree of user interaction. The adaptation process will prompt the user with alternatives and suggestions from which the user can select or confirm. This is, therefore, partially in line with CADRE (Hua et.al. 1993) but more similar to that proposed by SEED (Flemming et.al. 1994 a & b). Chapter 8 provides a more detailed discussion. Table 1 summarises and distinguishes features from other comparable systems.

FEATURE	PROPOSED SYSTEM	OTHER SYSTEMS
Case Storage	Suggests a multimedia storage of cases. An Object Oriented feature storage for indexing, CAD file storage, graphic file store (video & scanned images), database of costs, building regulations etc.	Comparable to CASECAD but distinguishes clearly from all other systems such as SEED, CADRE etc.
Case Indexing	An Object Oriented perspective base structuring of cases is proposed with a flexible multi-level indexing scheme. It has four main perspectives of Architectural, Structural, Services & Estimating. Case indexing will be hidden from the user.	Distinguishes clearly from all other systems. But, CASECAD & SEED proposes an object oriented indexing feature hidden from the user.
Case Retrieval	Provides automatic retrieval of a set of cases ranked according to the degree of match to a set of weighted retrieval criteria (brief). Allows retrieval based on a set of clues input by the user. Therefore, high flexibility of retrieval. Uses a similarity metric for the analysis the degree of match.	Vaguely comparable with SEED & CASECAD, but differentiates from CADRE which argues for an user selection of case.
Case Presentation Contd./	The system has the multimedia case presentation capability thus enabling greater visualisation and understanding of the design.	CASECAD uses multimedia case presentation technique but only in the form of attribute - value pairs, 2D and 3D CAD images.
Case Adaptation	Uses four main adaptation processors, viz. : 1. Architectural Adaptation 2. Structural Adaptation 3. Services Adaptation 4. Cost Adaptation	Most systems avoid adaptation and allows it purely for the user. SEED proposes an interactive adaptation (Architectural Design) procedure while CADRE & ACABAS proposes dimensional topological adaptation.
Domain	The prototype system is proposed for industrial buildings, but if successful can easily be adopted for other types of buildings. Deals with a comprehensive range of design aspects including Architectural design, Structural girding, Services System Selection and Cost Planning. Thus, first system to deal with multiple domains in an integrated CBD environment.	ARCHIE, ARCHIE II, MEMORABILIA, CADRE & SEED are in the domain of Architectural Design. CADSYN, CASECAD, STRUPLE deals with structural analysis and design. ACABAS caters for architectural design and structural girding. Most systems are developed for office buildings, court house, museums, apartment blocks etc.

Implementation	Proposes as an integration of CBR with OOKB development environment that facilities the use of CAD and Databases. It shall be implemented in MS Windows environment (PC based).	Most systems have been implemented in an UNIX environment (or XWindows). Some uses CBR development shells while others use common LISP, AutoLisp, C and similar AI languages.
Learning	The system learns by storing new designs generated by the system itself (Dynamic memory). It avoids tedious indexing, artificial storage of cases to the case library. It grows with the experience of the users forming a repository of co-operate experience of the user organisation.	Most systems have to rely on a considerable effort to build a memory of cases. Natural learning has been limited to a great extent.

Table 1 Comparison of NIRMANI with other CBD Systems in Construction

5. Case Memory Organisation & Retrieval

The case memory of the proposed system is organised as a multimedia case store consisting of the following forms of representation schema;

1. A library of cases structured as an *object oriented hierarchy with attribute-value pairs.*
2. Relevant 2D CAD images of the layout plans and 3D CAD images of the industrial buildings corresponding to each case.
3. Video clippings describing various important aspects and functionality of the building.
4. Photographic, scanned or video still images of various parts and elevations of the building.
5. Textual descriptions of various design aspects, expert comments and designers comments on the design.

The object oriented hierarchical representation forms the core of the case library structure with each case having links with the other forms of multimedia representations as depicted in Fig. 3.

Each case in the case library is hierarchically classified, primarily using the perspectives of the four main professions involved in the design process. i.e. in to the perspective of : architect, structural engineer, services engineers and quantity surveyor (estimator). Each perspective is then further classified so as to provide information to the each of the professions in the form they require.

However this representation may encourage redundancy. But, this could be effectively reduced with the use of multiple inheritance characteristics attributable to object orientation. The hierarchical representation of a case also provides a natural indexing schema for the retrieval of case information.

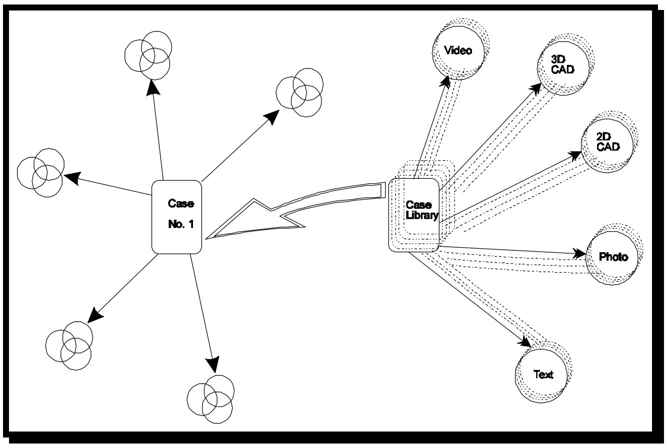

Fig. 3 Multimedia Case Store

The user is provided with 3 main modes of case retrieval. i.e. *Use of Design Brief, Clues, User Information.* The first mode provides the primary form of retrieval while the latter two enables more specific form of case retrieval where the user vaguely knows the specific case he/she wants. When using the design brief mode the user is required to enter the requirements of the building he/she needs. It is done in two levels : *Primary Retrieval* and *Secondary Retrieval.* Primary Retrieval criteria (e.g. Total Cost, Gross Floor Area, Occupancy, Shape, etc.) represents high level information whereas Secondary Retrieval criteria (e.g. Functional requirements in detail, Elemental costs, Elemental specifications, etc.) represents more detailed and specific low level features of the expected building. Each of these retrieval criteria can be relatively prioritised by attaching a weighting to each criterion.

6. Case Adaptation

Knowledge in the system can primarily be categorised as :

1. Automatically Upgradable Knowledge :- This constitutes cases stored in the case library and the associated Multimedia storage of information. This type of knowledge is automatically upgraded as a learning process.
2. Relatively Static Knowledge :- This constitutes the domain specific knowledge represented as rule and objects. These are upgradable only by the case-base administration or the system administrator.

The latter type mainly represents the domain specific adaptation knowledge. Adaptation knowledge can be formulated in two main ways (Hua & Faltings, 1993).

1. By categorising the case as instances of prototypical designs which can simply be reinstantiated. Adaptation knowledge can then be stored as *case category specific knowledge.* However, this raises the question of why cases are required at all, as prototypes could fulfil the same function (to a great extent).
2. By providing specific adaptation knowledge which modifies aspects of cases instead of regenerating or reinstantiating them.

The concept of prototypical cases and relevant adaptation knowledge is more amenable to CBD systems in domains such as mechanical systems design (Tanaka et.al., 1993). However, in domains such as building design where prototypical designs are difficult to identify the use of specific adaptation knowledge is more relevant. This is because there could be numerous differences between individual design cases of a particular design prototype (category) and adaptation knowledge required for all these differences cannot practically be generalised or classified. In the CBD systems for the construction industry, varying approaches for storing adaptation knowledge has been adopted. CADRE (Hua et.al. 1993) stores specific adaptation knowledge along with cases whereas CADSYN (Maher & Zhang, 1993) uses a separate generalised domain knowledge base in the form of decomposed subsystems and elimination constraints.

The use of specific adaptation knowledge is proposed as the method of formulating adaptation knowledge as opposed to adaptation of prototypical cases for the reasons explained before. However, the use of prototypical cases could be a useful method for case adaptation in the case of future expansion of the system incorporating different types of buildings.

One way to implement adaptation is to completely decompose the design case into design elements and sub elements, as implemented in CADSYN (Maher & Zhang, 1993). But this may cause additional design constraints due to interdependencies and interrelationships of design elements. For instance, a building design satisfies functions in many different abstractions such as structure (structural system of the building) spaces (functional spaces of the building) and circulation (occupant movement patterns within the building). Hence, adaptation of any of these in isolation may violate performance of other abstraction. But on the other hand, all abstractions cannot be adapted together. This requires adaptation to be carried out in an intermediate way, i.e. to limit decomposition and to compensate introduce user interaction. Further, an iterative process that operates in a cycle may be required in order to satisfy new constraints established due to modifications. Thus, a***n iterative and interactive problem decomposition and constraint satisfaction adaptation approach*** is suggested (as detailed in Fig. 4).

Once a case is selected all its features, characteristics design and context based knowledge are mapped directly to create a new case, exactly the same as the previous case. The new case would then be updated with the information provided for the retrieval. The mapping process enables the *design brief* to be developed on the guidelines of the original case (selected case). On this phase of developing the *design brief* the user is offered the opportunity of changing the characteristic, feature, design or context based knowledge. By doing so. the user would be creating a unique specification for the new design.

On completion of the *design brief* development, the system shall identify the differences between the original case and the new case, thus establishing design constraints. The system then uses a constraint satisfaction approach for all subsequent adaptations. Problem decomposition is used to decompose the design problem into sub problems, viz. Architectural, Structural Services and Estimating and each sub problem is further decomposed into another layer.

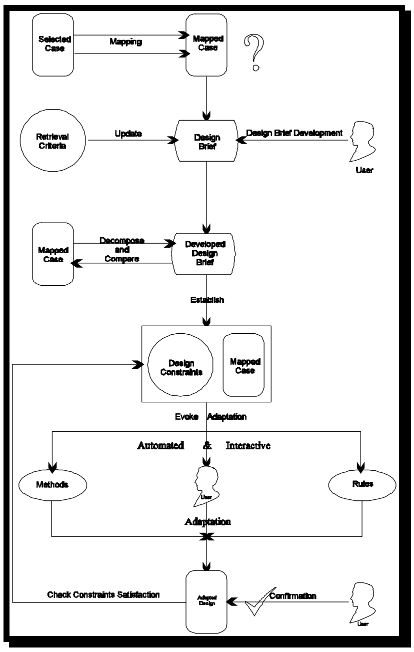

Fig. 4 Overview of the Adaptation Process

7. Conclusions

The NIRMANI system will enhance the design process in many ways.

1. It effectively reduces the time required to produce an outline design to few hours.
2. Avoids premature bias to a particular initial design as designs could be generated cost effectively. This enables comparison of many design alternatives in terms of design features, appearance, usability and cost.
3. Reduces buildability problems of design through design optimisation *(design to construct)* by avoiding construction problems encountered in previous cases. Thus, negative experiences could be used to provide positive improvements in terms of design and cost.
4. Encourages better design team co-ordination and communication as the system considers all aspects of design and cost. The system is better utilised if all parties to design and estimating participates in using the system.

5. Enables designs to be generated within the budget *(design to cost)*. The generation of cost plan allows cost to be monitored in initial design development while the cost plan of the accepted design provides the basis for further design development.

The conceptual model developed and related developments elsewhere (Maher & Zhang, 1993; Schmitt, 1993; Hua & Faltings, 1993; Kolodner, 1993) had proved CBR as a powerful methodology for KBS development for the construction industry. The system has well achieved integration of design, estimating & construction processes by the fusion of design and estimating in a single system and tracking back the construction experience to design.

The system grows with the experience of the organisation providing a corporate experience bank for the design organisation. The use of previous design and construction experience helps to achieve ***"best practice"*** in design by avoiding repetition of previous mistakes. An interesting facet of the system is that it allows the development of the design brief from a basic set of requirements to a detailed and comprehensive brief while enhancing the understanding of the design by the client through the use of multimedia visualisation capabilities and the understanding of requirements by the design team. Moreover, the entire CBD process is interactive, giving the user sufficient authority and control to guide the design process and achieve creativity.

8. References

Aamodt, A.,and Plaza Enric, (1994), Case-based reasoning: Foundational issues, methodological variations and system approaches, *The European Journal on Artificial Intelligence, AICOM,7 No.1.*

Akin, O.,(1986), *Psychology of architectural design,* Pion, London.

Alshawi, M.,and Underwood, J., (1994), Information analysis approach for integrating design and construction, Dept. of Surveying, University of Salford.

Aouad, G.,Cooper, G., Brandon, P.S., Brown F., Child, T., Ford, S., Kirkham, J., Oxman, R., and Young, B., (1993), Integrated databases for design and construction.

Brandon, P.S.,(1984), Cost vs. quality : A zero sum game ? In : Powell, J.A., et. al. (ed.) Designing for building utilisation, E & FN SPON, London, pp. 108-123.

Chandrasekeran,B.,(1990), Design problem solving: A task analysis, *AAAI, AI Magazine,* 59-71.

Cutkosky, M.R., and Tenenbaum, J.M., (1990), A methodology and conceptual framework for concurrent product and process design, mechanism and machine theory, 25(3), pp.365-381.

Domeshek, E.,and Kolodner, J., (1992), A case-based design aid for architecture. In *Artificial Intelligence in Design,* edited J.Gero. Boston: Kluwer.

Flemming, U.,(1989), More on the representation and generation of loosely packed arrangements of rectangles, In *Environment Planning, Building, Planing and Design,* 16, pp. 327-359.

Flemming, U.,(1994 a), Case-based design in the SEED system, *Automation in Construction 3.*

Goel, A.,Kolodner, J. L.; Pearce, M.; Billington, R.; and Zimring, C. (1991), Towards a case-based tool for aiding conceptual design problem solving. In E.R.Bareiss, edited *Proceedings : Workshop on case-based reasoning (DARPA),* Washington, D.C. San Mateo, Morgan Kaufmann.

Hillebrandt, P.M., (1985), Economic Theory and the Construction Industry, Macmillan.

Hua, K.,and Faltings, B., (1993), Exploring case-based building design-CADRE, In: *AI EDAM, Vol. 7, No.2,* pp. 135-143, Academic Press Limited.

Hua, K.,Faltings, B., Smith, I., Schmitt, G., and Shih, S.G., (1992), Adaptation of spatial design cases, In: *2nd International conference on AI in design,* CMU, Pittsburgh, pp. 559-575.

Kartam, N.A.,(1994), ISICAD: Interactive system for integrating CAD and computer-based construction systems, In: *Microcomputers in civil engineering, Vol. 9,* pp. 41-51.

Kolodner, J.L.,(1983a), Maintaining organization in a dynamic long-term memory, *Cognitive Science* 7(4).

Kolodner, J.L.,(1993), Case-Based Reasoning, Georgia Institute of Technology, Morgan Kaufmann

Maher, M.L.,and Balachandran, B., (1994 c), Multimedia approach to case-based structural design, In: *The journal of computing in civil engineering, Vol. 8, No. 3,* pp. 359-376, July.

Maher, M.L.,and Zhang, D.M., (1991), CADSYN: Using case and decomposition knowledge for design synthesis, In: *Artificial intelligence in Design*, Gero, J., (ed.).

Marir, F.,Watson, I.D., (1994), A categorised bibliography.

Oxman, R.,and Oxman, R., (1993 b), PRECEDENTS: Memory structure in design case libraries, In: *CAAD Futures '93,* Flemming, U., and Wyk, S.V., (ed.), pp. 273-287.

Pearce, M.,Goel, A.; Kolodner, J. L; Zimring, C.; Sentosa, L.; and Billington, R. (1992), Case-Based design support: A case study in architectural design. *IEEE Expert* 7(5), pp 14 -20.

Porter, B.W.,and Bareiss, E.R., (1986), PROTOS: An experiment in knowledge acquisition for heuristic classification tasks. In: *Proceedings of the First International Meeting on Advances in Learning (IMAL)*, Les Arcs, France, pp. 159-174.

Raftery, J.,(1991), Principles of Building Economics - An Introduction, BSP Professionals, 1991.

Riesbeck, C.K.,and Schank, R.S., (1989), Inside case-based reasoning. *Northvale, NJ: Erlbaum.*

Rosenman, A.,Gero, J.S., and Oxman, R.E., (1991), What's in a case : The use of case bases, knowledge bases and databases in design, In : Schmitt, G.N., (ed.) *CAAD Futures '91*, pp. 285-300.

Rutherford, J.H.,and Maver, T.W., (1994), Knowledge-based design support, In: *Automation in construction 3,* pp. 187-202.

Schank, R.C.,(1982), *Dynamic memory: A theory of learning in computers and people*. New York: Cambridge Univ. Press.

Schank, R.C.,and Abelson, R.P., (1977), *Scripts, plans, goals and understanding.* Erlbaum, Hillsdale, New Jersey, US.

Schmitt, G.,(1993), Case-based design and creativity, *Automation in construction, Vol. 2,* pp. 11-19

Schmitt, G.N.,(1993 b), Case-based reasoning in an integrated design and construction system, In: *The International Journal of Construction Information Technology, Vol. 1, No. 3,* pp. 39-51,

Simon, H.A., (1973), The structure of the ill structured problems, *Artificial Intelligence 4,* pp.181-.

Slade, S.,(1991), Case-based reasoning: A research paradigm, AI magazine, pp. 42-55.

Tanaka, T.,Hattori, M., and Sueda, N., (1993), Use of multiple cases in case-based design, In: *Proceedings of I.E.E.E. Computer Society,* pp. 233-239, 1993.

Turner, J.A.,and Tsou, J.Y., (1993), "Using an object oriented system and a conceptual building model to represent architectural information during early design phases", *Proceeding of the 5th international conference (V-ICCCBE),* Computing in civil and building engineering, Anaheim, Cal, U.S.A., pp. 1175.

Watson, I.D.,and Marir, F., (1994), Case-based reasoning: A review.

Watson, I.D.,Brandon, P.S., and Basden, A., (1991), EMMY: an expert system for predicting maintenance for housing associations, In: Bezelga, A., and Brandon, P.S. (ed.) *Management quality and economics in building,* pp. 1603-1611, E & FN SPON.