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Issues on Horizontal Integration for Design

Problèmes de l'intégration horizontale dans les projets

Fragen der horizontalen Integration beim Entwerfen

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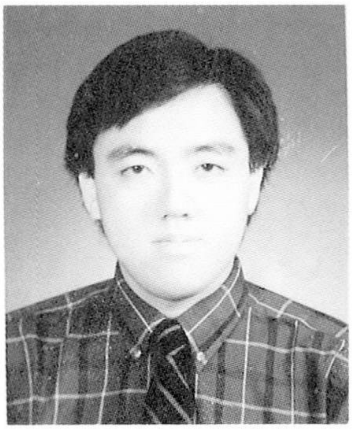

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SUMMARY

The benefit of having the input of various expert domains at the preliminary conceptual stage cannot be overemphasized. In an integrated design environment the issue is essentially that of integration to allow different expert domains to participate opportunistically in the conceptual design process. A system architecture that permits active communication and effective control of domain activities is proposed. The system architecture is modelled after the blackboard architecture of problem solving and augmented with proper representation models for an overall 'soft control' that allows subdomain design activities and domain-to-domain communication.

RÉSUMÉ

On ne soulignera jamais assez les avantages de pouvoir accéder à divers domaines experts au moment de la phase conceptionnelle des projets. Dans un milieu d'études intégrées, la question est de savoir comment faire appel, en fonction d'un besoin spécifique pour un projet, à ces différents domaines de connaissances. L'auteur propose une architecture de systèmes qui permet d'exercer une communication active et un contrôle efficace dans chacun des domaines d'activité. Cette architecture a été développée d'après la méthode de résolution des problèmes, calquée sur le principe du "tableau noir", et comporte des modèles représentatifs appropriés pour une "commande douce" généralisée; cette dernière permet d'effectuer des travaux d'études dans les sous-domaines et de communiquer entre les domaines.

ZUSAMMENFASSUNG

Die Vorteile der Verfügbarkeit verschiedener Expertengebiete in der konzeptionellen Entwurfsphase können nicht genug betont werden. In einer integralen Entwurfsumgebung stellt sich das Problem, wie solche unterschiedlichen Wissensgebiete nach Bedarf zum Entwurf herangezogen werden können. Zu diesem Zweck wird eine Systemarchitektur vorgeschlagen, die aktive Kommunikation und eine wirksame Kontrolle in den einzelnen Gebieten ermöglicht. Sie wurde gemäss der Problemlösung nach dem Blackboardprinzip entwickelt und enthält geeignete Darstellungsweisen für eine "weiche Steuerung", die Entwurfsaktivitäten in Untergebieten und Kommunikation zwischen Gebieten erlaubt.

1. INTRODUCTION

The existing successful Knowledge-Based Expert Systems (KBES) focused mainly to solve problems of single domains of which they are designed for. Although they are functionally very efficient, they are limited in the perspective of the problems to be solved. This is contradictory to the nature of most practical problems. Many of the problems in reality require more than the input of a single domain. For example, in designing a chair, although the designer may have successfully designed the chair conforming to some design requirements pertaining to the shape, colours, and appearance; the design would further require stress analysis to determine on the suitability of the material chosen for the intended weight of the user and the stability of the chair for normal usage positions. These analyses are apparently beyond the capability of a chair designer who is not expected to possess knowledge of these areas.

Capitalizing on the success of many KBES, researchers worldwide are focusing on integrating several individual KBES for a common problem domain to arrive at probable global satisfying solutions. One of the main area of testing this idea of problem solving engaging integrated KBES is the building design domain. The attractiveness of the problem domain lies in its inherent involvement of different experts.

This paper discusses the building design problem, highlights several integrated design systems, and presents a system architecture addressing a different approach for integrated design environment.

2. BUILDING DESIGN

Building design has been the popular domain of study for integrated design system due to its ill-structured problem nature and the involvement of many professionals on the design of the final artifact. Any building from its inception stage to its completion requires the services of architects, engineers, quantity surveyors, builders, financial advisors, and many others. However, not all professionals are involved at all phases of the building design process. Preliminary investigation requires the services of quantity surveyors and building economists to produce feasibility study for the building project. At the conceptual design stage, basically the architects and the engineers will work together to conjecture probable physical descriptions of the building. Their duties will carry over to the preliminary and detail design phases where the detail analysis of the design will be carried out to eliminate any problems and for the production of final design description. During the construction phase, builders as well as project planners will be employed.

Effectively the entire design process can be broken down into the following three stages:

1. **Conceptual Design.** The building as a whole is synthesized with the available information and design brief. Major components and concepts are developed at this stage. Work at this phase is subject to revision on the detail implementation, but majority of the decisions on the final product would have been made.

2. **Preliminary Design.** Professionals will attempt to study the implications of various

plans for the building. This could involve studies of different structural schemes, mechanical systems, electrical systems, overall building configurations, and others.

3. **Detail Design.** The major concern at this phase would be the production of details for the actual construction of the artifact. Many aspects of the design would have been finalized and any modifications to the design would be costly to rectify.

From the above descriptions of the building design phases, it can be seen that at the conceptual design phase the active involvement of various professionals is crucial to a successful design. The participation of various professionals can be shown schematically in Figure 1.

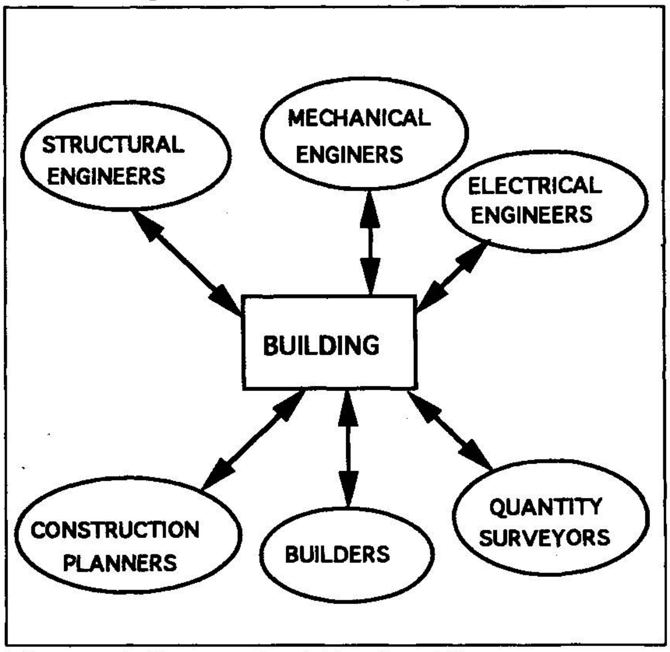

Figure 1 Conceptual Design Phase

With the success stories of KBES in solving problems of specific domains, researchers are aiming to integrate different expert systems to arrive at the globally acceptable design solution for a similar artifact. Each of the expert systems is seen to be effective in offering partial solutions to the whole design problem within the areas of their expertise. This approach requires a process of breaking down the design task into subtasks and allocating the subtasks to the appropriate KBES. Next section highlights some of the integrated design systems and the different approaches adopted by these systems to integrate various KBESs to design.

3.0 INTEGRATED DESIGN SYSTEMS

3.1 Different Approaches to Integrated Design

Jens-Pohl et al.[1] proposed an ambitious integrated design environment which attempts to integrate project program and databases of design information within an intelligent computer-based design environment. The environment consists of basically three components: an intelligent CAD DBMS; an Expert Design Generator; and, a Multi-Media Presentation Facility. The expert design generator essentially is made up of modules of Intelligent Design Tools that are coordinated by a Blackboard control system. The intelligent design tools perform the tasks of mechanical system design, structural system design, and other essential design tasks. While the multi-media presentation facility assists the user in visualising and understanding the design, the DBMS is designed to house the information on prototype buildings and site information. The entire project is aimed at a total computer assisted design environment, where the computer plays the central role in the development of the design solution.

Another integrated design environment that utilizes the blackboard model of problem solving in coordinating design solution process is the Integrated Building Design Environment (IBDE) at Carnegie Mellon University[2]. The environment consists of seven distinct components: ARCHPLAN, CORE, STRYPES, STANLAY, SPEX, FOOTER, and CONSTRUCTION PLANEX. Each of the KBES performs specific functions where ARCHPLAN tackles the development of preliminary design brief; CORE aims in the planning of the service core; STRYPES performs preliminary structural system configuration; STANLAY lays out the structural systems and performs preliminary structural analysis; SPEX continues with the preliminary design of the structural elements; while FOOTER designs the foundation system; lastly CONSTRUCTION PLANEX will assist in the construction planning.

The seven processes (as named) are actually standalone KBES that can perform their tasks efficiently without acknowledging other KBES provided appropriate design information is available. Some of the processes or KBESs are actually developed before the IBDE while others are specifically developed for the environment. Their participation in IBDE is coordinated by a status blackboard and controlled by a controller. Though a comprehensive environment which addresses the unique characteristics of building design, IBDE essentially, with its processes are envisaged to be located in different workstations, tackles the building design problem in a linear, sequential manner.

The two examples have illustrated the popular approaches normally used for the development of integrated design systems. In one case a central database is used to facilitate the exchange and the communication of design information from one design system to another and with one another within an environment. The design systems are independent of each other in terms of addressing the design problem and the participation in the design process. This is the approach adopted by Jens-Pohl et al. Often, a more efficient integrated system maybe derived for a specific problem domain through incorporation of design processes and directly addressing the design system. IBDE was planned to be such a system. Nonetheless, the integration of IBDE is essentially linear and sequential with the domains integrated discretely. This method is useful at the detail design phase but has not addressed the actual design scenario at conceptual design phase.

3.2 Typical Integrated Design Architecture

Previous section has illustrated two prototypes of integrated design systems for building design. Generally, an integrated design system consists of the following four major components:

1. *A Database.* This database serve as the storage for the global descriptions of the design artifact represented hierarchically. There may be more than one database if the system calls for it.

2. *A knowledge base.* The knowledge base consists of the knowledge of a particular domain. There should be more than one domain in an integrated design system. Each of the knowledge base may adopt different knowledge representation model. Primarily they provide design heuristics for the domains they are responsible for.

3. *An inference engine.* Inference engines are designed to work with the representation model of each knowledge base. The inference engines are to reason on the problem and to arrive at solutions using the knowledge base.

4. *A blackboard.* There may be more than one blackboard in an integrated design system with each blackboard performs specific functions. Normally a control blackboard is designed to oversee the activation of different knowledge bases. It will identify which knowledge base to activate based on the conditions it has and the status of the problem appropriate for that knowledge base to contribute to the solution process. In some cases a status blackboard is employed which is responsible for the status of processes.[3]

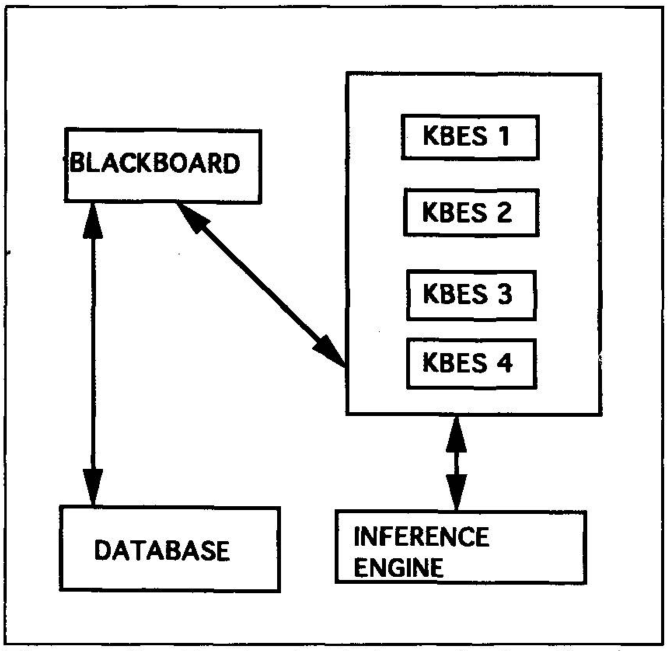

Figure 2 Typical Integrated Design Architecture

Figure 2 shows the general architecture of an integrated design system.

4.0 EFFECTIVE DESIGN INTEGRATION

4.1 Issues for Effective Design Integration

Instead of employing integration at the detail design stage, it is arguable that the most suitable phase for the involvement of various design experts in the domain of building design is the conceptual design phase. Decisions that affect approximately 80% of the total cost of a building are often made at this conceptual design phase.[4] It is conceivable that the large proportion of crucial design decisions at such an early stage in the design of a building would results in costly remedy later on should errors occur. An integrated design system should emulate the conceptual design phase during which professionals from different disciplines make their expertise available to assist in the formulation of the design artifact instinctively and opportunistically.

The integration of various expert domains at the conceptual design phase will be different from the integrated design systems mentioned in the previous section. Notably are the following differences:

1. Instead of a linear, sequential integration, a simultaneous and horizontal integration should be implemented. This would allow different domains to contribute to the overall design as the design information is becoming sufficient in their domains. Each of the domain will be aware of the status of the intermediate

partial design solutions and will act accordingly.

2. A lower level of control can be realized through the delegation of 'soft control' to the individual expert domains. The advantage of such setup would be to allow the individual domain to trigger the execution of other appropriate domains to contribute to the design solution process; then the first domain will act on the generated design information.

3. Communication will be divided into two levels. The first level will be the global design status and the second level is at the domain level. Global level communication is defined as that between the global objects base and the blackboard. Domain level communication is activated through the proper structuring of design heuristics and the provision of rich knowledge representation model.

The emphasis of the horizontal integration approach is the active, spontaneous, and opportunistic response of the expert domains. A system with the capability to allow such integration will serve well the problem of the conceptual design phase; that of lack of initial design information, and spontaneous contribution to the problem solving process. Instead of waiting for design information to be made available, a domain will seek out next proper domain to contribute to the design information thus enhancing the original design information to enable it to react to. This is representative of the actual design scenario as described in previous section.

Clearly, the functionality of such a system is beyond the problem solving paradigm advocated by blackboard models of problem solving. Typically blackboard systems are sequential though the knowledge will be rich enough to reason on the status of problem and to determine the next course of action, it remains that the system will access a 'central command post' which is not versatile enough for the problem solving approach desired in the previous paragraphs. Nonetheless it offers a good starting ground for the system architecture described in the next section that attempts to address the condition of spontaneous and opportunistic response of expert domains.

4.2 Integration with Active Participation

This section is structured to present the proposed system architecture. A few issues must be addressed with respect to the discussion of an integrated system. Figure 3 shows the overall system architecture with the necessary components. Essentially the system consists of a control blackboard, a global objects base, and various knowledge bases.

1. ***Global Objects Base.*** The major deviation from the conventional blackboard model of problem solving is the representation of the problem domain using objects and the development of hierarchical structure of these objects to represent different levels of partial solutions. The object representation allows the mapping of the global objects with that of the individual knowledge bases easily. This facilitates communication among knowledge bases as well as with the global objects. This represents a major difference between hierarchical representation in a status blackboard and the global objects base. Where a status blackboard

records the status of global solutions and make it available for the control blackboard to decide on next course of action; a global object will determine independently of the next domains which will contribute to the current design information. Status of the global objects can be determined readily by a control blackboard. Hierarchical structure of the global objects also allows status report of the partial global solutions to the control blackboard.

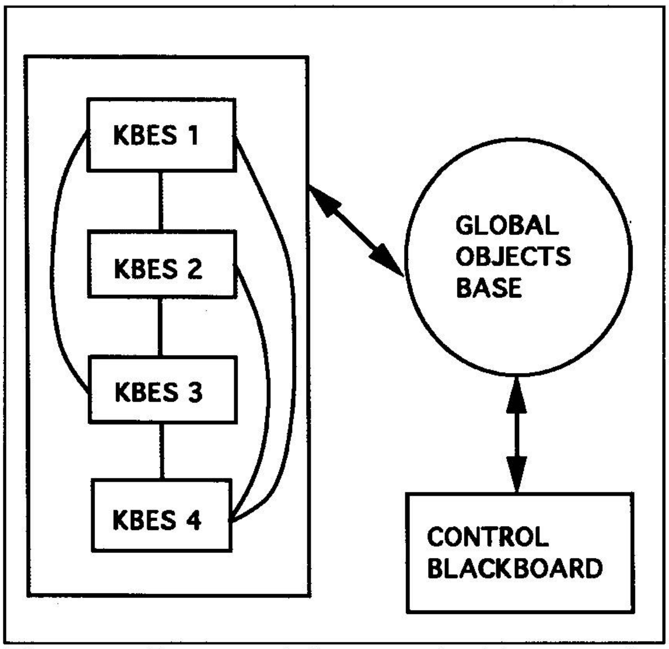

Figure 3 Proposed System Architecture for Integrated Design

2. ***Control Blackboard.*** At the core of the system architecture is this control blackboard. Rather than controlling the actions and the recording of status of solution process, the blackboard determines domain objects status, maps the domain objects to the global objects, checks on the global objects base to determine on their status and translates that into universal partial solutions to compare with the global solutions. It has no active function of activating appropriate knowledge bases for further actions. But it has the important task of determining the degree of completion of the global solutions. As communication and activation of knowledge bases are delegated to each domains, the control blackboard reasons at the global level.

3. ***Knowledge Bases.*** Each knowledge bases is composed of its own inference engine and expert knowledge. Object representation is used to ensure uniform representation and to enable mapping to the global object base. Objects at the domain level of a knowledge base, which is augmented with rules to guide on the solution process, decide on whether the design information at any time of the solution process is sufficient for it to contribute to the global solution. If not, the domain objects will determine on what are the design information it needs for it to contribute to the current solution status. It communicates directly with other domains that can contribute to its collection of design information for it to take action.

4.3 Controlling Solution Process

Unlike most integrated design systems which have in the heart of the systems blackboards that watch over the solution process, keep records of activation of knowledge sources (a term used widely in blackboards which essentially means knowledge bases), and determine the next course of action and the knowledge source to activate, the proposed system, described in previous section, delegates the essential control of the solution process to the individual domain objects.

This translate into the requirement for an effective implementation plan. The knowledge bases will have to be designed conforming to the global objects in the global objects base. This is seen as necessary in order to have effective communication between the global objects and the domain objects. A derived benefit of the implementation is the uniform representation of the objects in various domains; hence, enhancing the domain level communication.

4.4 Object Representation

Object representation is employed in both the global objects base and the knowledge bases because of the flexibility of the model. It allows hierarchical structuring of the solutions and permits the eventual mapping from domain to global objects. Coupling with rules, the objects can effectively determines the next course of action even at the domain level. Ease of expanding the object descriptions also was taken into consideration for choosing this knowledge representation model.

The global objects base can be expanded incrementally as more knowledge bases are added to the system. These knowledge bases will inevitably introduce new objects to describe their domain objects which would form additional descriptions for the global objects base.

5. DISCUSSIONS AND CONCLUSION

An attempt is described in the paper on how to effectively introduce opportunistic and spontaneous style of participation of several expert domains in an environment. Experience from the development of such a system has called for careful design and implementation of the global objects base and the blackboard.

Knowledge representation model has been given very special attention in the development of the system, it is seen as a crucial and very complex task. The proposed system has not taken advantage of the clear and explicit representation of the solutions as offered by the conventional blackboard systems. The detail implementation of blackboard is outside the scope of current discussion.

However, active participation and the activation of appropriate domains at the domain level is achieved through the sacrifice of this obvious advantage of blackboard models of problem solving. In addition the proposed system has advocated a representation using objects which can be very effective in hierarchical structuring of the partial solutions. In spite of, it has incorporated a blackboard to check on the status of the global solution objects.

There remain several issues need to be taken care of for effective implementation of the system architecture. Hardware constraint is a major factor considering the speed of execution since the knowledge bases are expected to be resided within a single computer system. System memory requires for such an environment will also be unusually demanding. Complexity in structuring the knowledge and objects cannot be overemphasized too.

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