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Knowledge-based System to Support Architectural Design

Intelligent objects, project net-constraints, collaborative work

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The architectural design business is marked by a progressive increase in operators all cooperating towards the realization of building structures and complex infrastructures (Jenckes, 1997). This type of design implies the simultaneous activity of specialists in different fields, often working a considerable distance apart, on increasingly distributed design studies.

Collaborative Architectural Design comprises a vast field of studies that embraces also these sectors and problems. To mention but a few: communication among operators in the building and design sector; design process system logic architecture; conceptual structure of the building organism; building component representation; conflict identification and management; sharing of knowledge; and also, user interface; global evaluation of solutions adopted; IT definition of objects; inter-object communication (in the IT sense).

The point of view of the research is that of the designers of the architectural artefact (Simon, 1996); its focus consists of the relations among the various design operators and among the latter and the information exchanged: the Building Objects.

Its primary research goal is thus the conceptual structure of the building organism for the purpose of managing conflicts and developing possible methods of resolving them.

***Keywords**. Collaborative Design; Architectural and Building Knowledge; Distributed Knowledge Bases; Information Management; Multidisciplinarity.*

Scientific bases

At the beginning of the new millennium, design companies, especially architectural design companies, are characterised by a new advanced working method, Collaborative Design (Howard, 1997; Kvan, 2001), by which is meant a design process characterised by a continuous exchange of design information among all the operators involved, even across the customary interdisciplinary borders, and by asynchronous and/or concurrent working methods.

Two paradigms

In this field of investigation, two different schools of thought have emerged over time: the first , defined as the Conventional Method, is to provide a low-level shared data exchange platform enhanced by specific applications for each discipline (Gero, ;Björk, 1992); the second, calledas Collaborative Design, is based on a semantically rich Common Knowledge Base upon which the various professional profiles may draw, Fig. 1.

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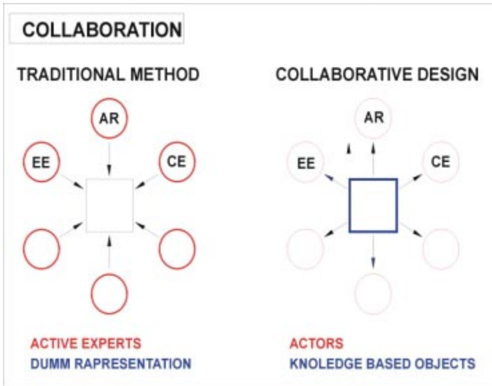
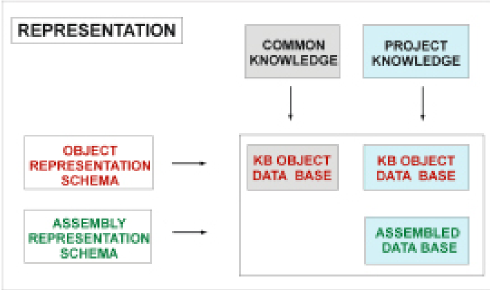
Figure 1 (left). Two paradigms of Collaborative Design.

Figure 2 (right). The structure of representation.





The following research may be included in the first paradigm:

STEP - The main aim is stated in the name - STandard for Exchange Product data model. Its first and second implementation in the building sector, although attaining draft status, have never become an ISO standards.

COMBINE - COmputer Models for the Building Industry in Europe. Although based on the STEP-EXPRESS to transfer the conceptual schema (object, type, definition) and the "neutral files" STEP to transfer object instances, it is a prototype specialized in evaluating energy and HVAC performance (Amor et al., 1995; and 1998) (fig 1 & 2).

OXSYS - Software commissioned by the Oxford regional health authorities, it was conceived as an aid in the integrated design of hospitals using a predefined "kit of parts", namely the Oxford system.

ICADS - A system based on a very small number of architectural objects (seven) which develops a set of controls according to the blackboard paradigm and a set of rule-based expert systems in the design of a building (Pohl and Myers, 1994).

The following systems may be considered as belonging to the second paradigm:

KAAD - Strongly design aid oriented (Galle, 1995). Its strengths: semantic richness, the large number of building components used, multiple inheritance, being open and scalable. Composed entirely of objects, also its graphic representation is additive. Allows constraints to be activated and de-activated, and new ones created. It does not determine a single top-down or bottom-up design flow (Carrara, Kalay, and Novembri, 1994).

EDM - Developed to represent a building having different levels of abstraction, building technologies and projected uses. These aspects are represented by the objects BOUNDED_SPACE, CONSTRUCTED_FORM and ACTIVITY, respectively. It too is open and scalable. One of its drawbacks is the separation of the representation of the building from its geometry.

BDA - Building Design Advisor. Comprises different integrated performance evaluation applications (such as DOE-2, Superlite, etc.). It has a unified and known interface, supplies a representation of shared data and envisages format exchange tools. It acts as a repository for the values produced by the different applications (Papamichael et al., 1996).

The first paradigm encounters the serious problem of the impossibility of modifying or increasing the applications, which are fixed like the shared data platforms at a low semantic level. They are often too generic. On the other hand, they are more practical to use and easier to implement.

The second runs up against the complexity implicit in the large number of complex object relations, and is characterized by a rough and ready implementation of objects and semantically rich relations.

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These two paradigms are closely linked with the algorithmic and IT problems involved in Collaborative Design. These include building constraint management, the automated or semi-automated solution of inconsistencies, as well as the complex organization of the system to allow the exchange and merging of contributions from all Collaborative Design participants.

All these aspects are only partially resolved by commercial packages and applications deriving from industrial initiatives, such as that of the Bentley System for the IFC.

Ongoing research

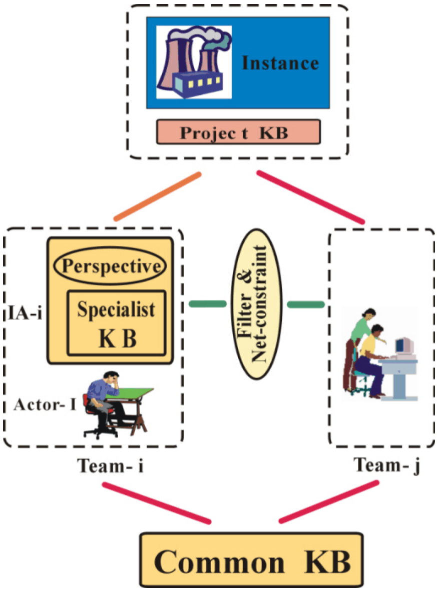
With regard to that previously explained, the research is placed in the second paradigm of Collaborative Design.

The Aim of the research is to develop instruments for a Collaborative Design through the management of knowledge. The knowledge which has been taken into consideration is that pertaining to the preliminary phase of building and architectural design, when the simultaneous collaboration of various professionals is most obvious and crucial.

We think that developing the component based on the designer's knowledge so as it is able to take into account the constraints and the consequences of each design decision, show up the inconsistencies and possibly suggest alternative solutions.

The structure of the software system model, which complies with the customary effective design processes, will consist of a set of systems themselves consisting of: Knowledge Bases, Data Bases, both graphics and network programs, an inferential engine, and Structures of Relations.

The latter consist of semantic and/or operating relations among the elements comprising a Building Object, with regard to a given physical phenomenon and/or a design object. The Structures of Relations are not necessarily systems external to the KBs. For example, the goal of achieving a correct coupling of objects is contained in the objects themselves which know which surroundings are desirable or denied or acceptable (fig 3 & 4).



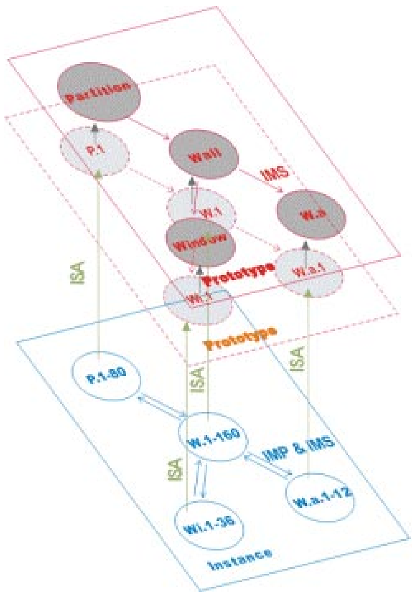


Figure 3 (left). Knowledge Bases and the Building Object.

Figure 4 (right). Relations among prototypes and instances for a typical wall.

The case of energy saving is different. This goal takes into account the entire Building Object and configures the Structures of Relations as a software System in its own right.

The Knowledge Base is constituted by:

- Common Knowledge Base of all participants (CKB);
- Specialist Knowledge Base, peculiar to each participant (SKB);
- Project Knowledge Base of the single project (PKB).

The three levels of the Knowledge Base are additive, Fig. 3.

Perspectives allow each operator to see only the relevant information in a building being designed ((the instance created from the Knowledge Bases).

The PKB was set up in addition to the conventional representation of objects in a Building Body as it was necessary for design purposes,. In fact, the need to create a new building component may arise. For example, in certain climactic conditions, there may be the need to define a new type of external wall, which cannot be derived from those of the CKB or from the SKB. It is useful to create this new wall because it will be in much demand during that particular project, although it does not necessarily go so far as to increase the other Knowledge Bases.

Even though it has been created from zero, it will be part of the KB's in order to take advantage of inheritance, geometric representation, constraint checks, the spatial congruence relations, interrelations with the other building components in the project as well as verifying their performances.

The same may occur when introducing new constraints. For example in health institutions for the aged, it is better if the bedroom is at least twenty metres from the lift; or in an art gallery it is better if the lighting is over a certain lux level.

The structure of representation of the Building Object

Each project has its own ADB (Assembly Data Base) that goes alongside the KB (given by CKB + SKB + PKB), since the two components are different: the PKB allows for a dynamic verification of the performance and constraints activated at the moment data is inserted or the creation of a new instance (Fig. 4) (both as a building component and as a constraint check); whereas the ADB allows for a rapid gathering of stated data, as the net surface of a floor to instant data about the project process (without utilizing the inheritance as its control) including the geometric data of the Building Object, allowing the spatial congruence of the objects comprising the B. O. to be verified.

The CKB that both the SKB and the PKB conform to, has the following structure: two independent systems, the Space System and the Technological System bound by " Structures of Relations" (Carrara, Fioravanti and Novembri, 2000).

The Space System is the structured set of equivalent classes to the space needed to carry out a specific activity. It is made up of two Domains: Environmental and Elementary Space. The first consists of spaces mainly contained by physical elements like its BUs and SUs (Building Units and Space Units) components; the second is made up of spaces that are not surrounded by physical elements like its ESs and PEs (Elementary Spaces and Partition Elements).

In the same way the Technological System or physical elements system is sub-divided into two Domains: Constructive and Row Materials. The former is made up of constructive building components capable of carrying out one or more functions whichgive a certain performance through its FSS and FE (Functional Sub-Systems and Functional Elements); the second is made up of materials that have only properties: the BE and RM (Base Elements Raw and Materials).

The division of the two Systems into two Domains is arbitrary for certain versos but functional for the sciences involved. The Domains of the Elementary Space and Row Materials have a lattice structure. The Environmental and Technology Domains have a semi-lattice structure since in the KB and in their constituent elements only "whole" (also known as IMS, Immediate Successor) unidirectional relations are present.

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This is how each element of the KB is able to have more than one “father element” and thus permits the multiple inheritance to be obtained. Thus with only a few simple elements many complex components can be obtained.

The challenge of the research is thus focused on the capacity to transfer knowledge to the objects, so that they acquire “intelligent” behaviour and become “active” design elements.

The “intelligence” of the objects comprising the Spatial System, the Technological System and the Structure of Relations lie in the possibility of:

- having a semantics, knowing what they are through a definition thereof, through the hierarchical structures to which they belong;
- providing explanations, not only on their state but also on their behaviour;
- possess rules of behaviour towards other objects, constraints, goals;
- having a coherent and accurate representation of the context, meaning by this the design phase and the applicational environment in which it is instanced;
- knowing its own positioning versus a reference system and also other objects (at any moment it is possible to verify the dimension constraints);
- being multi-hierarchical so that it can be ordered according to different criteria using Conceptual Clustering techniques (not only through properties explicitly defined in the object);
- varying its own IT structure to relate to objects having a different structure in other applications (polymorphism).

Above all, however, all these characteristics must be dynamic.

Conflicts and design objectives.

The capacity to provide explanations concerning several project or physical constraints is essential in order to resolve conflicts rapidly.

The resolution of conflicts as quickly as possible is a considerable advantage in improving the design process both temporally and costwise. Whenever a conflict is not identified in time and the design activities are continued in the meantime, the construction of the building object may be impaired by unsatisfactory solutions.

Not only, but also the capacity to provide explanations about a constraint not respected by another professional (or disciplinary sector) is a powerful aid in asynchronous design.

The Structure of Relations Filter has the task of correlating the representation of an element used in the ADB with another representation of the same element used in a different application. This occurs by transforming the structure of the IT representation of the component. Another application of the perspective is when we wish to regroup several components on the basis of “conceptual clustering” methods (Carrara et al.., 1995).

Implementation of the system model for Collaborative Design and conclusions

In the past our Research group has developed a support system for architectural design within only one working group, and thus with a single KB (Carrara, Kalay, Novembri, 1994), by using a frame language in LISP.

It has been used even recently by Kalay (1998), thanks to its effective four-tier hierarchical structure: frame, slot, facet and value,.

Everything described in the preceding chapters (our choice of the multi-Perspective Vs the multi-Modal representation, the fact that the operators of the design process vary in time and that all the skills are not known a priori) we must use computerized representation structures that are as flexible as possible.

From another viewpoint, with the experience acquired during the development of ad hoc software produced in-house at great cost in terms of resources, also therefore for basic software (e.g. for multiple inheritance, the creation of instances, to change the direct superclasses), it is preferable to adopt the standard ANSI structures of information technology representation.

The choice thus fell on CLOS as, in agreement with the findings of authoritative researchers (Zang and Norman, 1994; and several researchers at PARC), its use in the case of distributed KBs was considered more appropriate.

However, CLOS with its fixed three-level structure - frame, slot, facet -, seems to be more constraining that the pure four-level frame structure.

To get round this it was decided to transform also the slots and facets into objects, Intelligent Links (ILNK) which, depending on the validation provided in a given disciplinary area, project phase, SW application context, project manager and object creator, allow the object structure to be varied.

In this way we free ourselves from the " frame problem" due to a purely encodigism approach (Bickhard and Terween, 1995). The frame problem arises when too many objects are needed to fully describe a complex set or "word".

The development of this approach seems to promise well despite the large number of relations among objects (a reflection of the complexity of the design process): although it has to be performed manually, it is an exciting task.

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