25. What could Artificial Intelligence know about the knowledge involved in the design process?

Khaldoun ZREIK

CIMA
9, rue Barbanègre
75019 Paris, FRANCE

The nature of the knowledge involved in the design process is particular and incompletely known. Its control becomes very complicated owing to the large number of dynamic parameters and functions which define the relationships between one another. So we consider two relevant facts :

1. all knowledge involved in the design process could not have been foreseen ;
2. the help of computer technology in this domain is badly oriented.
Two major questions will be posed here :
what kind of design knowledge do designers explicitly master?
and which parts of it can computer technology represent today ?

This paper aims to build a simple panorama of the knowledge involved in the architectural design process. Actors, resources and corresponding classifications of this knowledge and also its dynamic distribution will be presented. It also throws light upon how important are artificial intelligence sciences and tools for the improvement of the design process computability.

Introduction

One can figure out that the knowledge involved in the design process is divided into three domains: the explicit-known domain, the implicit-known domain, and the domain of the unknown.

The explicitly known domain consists of a set of conventional modelled knowledge and heuristics which is rapidly expressed, easily represented and currently used or transferred to others. This domain of knowledge includes some part of intuitive knowledge and a large part of standard knowledge (technique, economics, regulation,etc.).

The implicitly known domain of knowledge includes all knowledge which can be felt but can not be expressed or formulated properly from the beginning. In fact this domain concerns the greater part of knowledge involved in the design process.

According to Zeisel (Zeisel 1981), design consists of three elementary activities which are imagining, presenting and testing. On the other hand, Heath (Heath 1989) considers that innovative or original thinking and decision are possible at every stage of the design process. Thus the nature of imagining or innovative thinking is rather implicit.

Today most CAD systems deal only with the explicitly known domain of knowledge so they don't take into consideration all knowledge involved in the design process.

Does one really need to model the implicitly known domain ?

In order to answer this question, many people are certainly endeavouring directly or indirectly to find out what exactly design process is about or at least what is to be seen or understood in this domain ? Furthermore what part of known knowledge will one be able to express clearly ?

Some research works have tried to bring some positive answers which in practice have never been very convincing.

On the other hand it has been proved that integrating all the knowledge which could be involved in the design process is not always interesting. Thus differences must be made between uninteresting knowledge and knowledge which can not be formulated or represented properly.

Otherwise one must identify this problem and must avoid that CAD systems take into account this relevant fact by introducing at least a high level of interactivity to enable users to choose and integrate the different types of knowledge they manipulate. Finally the question remains the same: what kind of knowledge could and must be integrated in a CAD or Intelligent CAD system ?

For these reasons we distinguish three kind of taxonomies to represent the knowledge involved in the design process: classical, professional and practical (see figure 1).

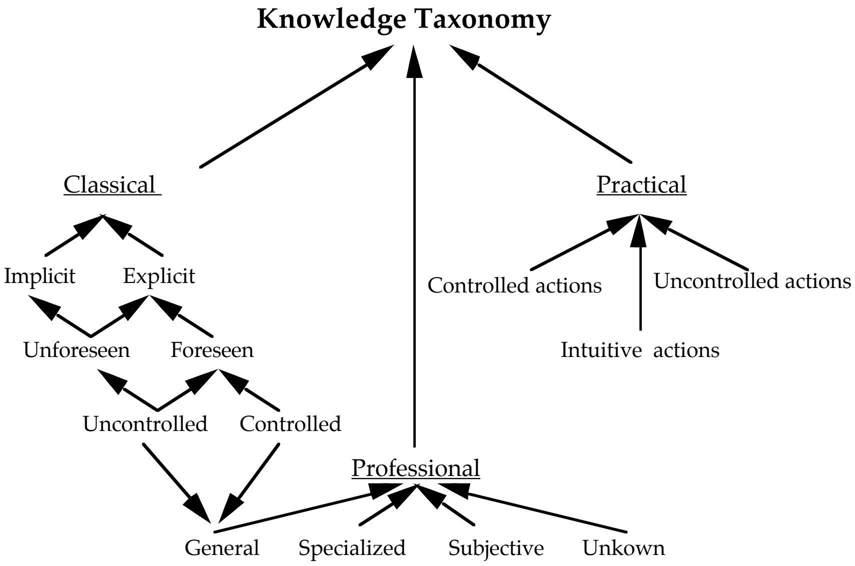


Figure 1. A knowledge taxonomy representation

A classical taxonomy of knowledge in design : A naïve point of view

In this paragraph we suggest a general and naïve definition of the explicit and the implicit parts of knowledge which may be manipulated by the designer.

Explicit Knowledge

It is the type of knowledge which the designer claims as to be able to express clearly. Two classes can be distinguished :

The Foreseen Knowledge: it is the set of knowledge considered necessary in order to carry out an action or a task. It can be controlled or uncontrolled. The knowledge is controlled when one knows explicitly *when, where and how* to use it in a design process. Otherwise it is uncontrolled.

Today most CAD systems use only controlled knowledge by means of the AI techniques (Brown et al. 88) some of them can even integrate a set of unstructured complete knowledge which could be considered as uncontrolled.

The Unforeseen Knowledge: it is absolutely impossible to foresee all details about knowledge and particularly when one deals with the uncontrolled part of knowledge.

In fact all uncontrolled knowledge (UK) can eventually become controlled knowledge (CK) in an advanced stage of the design process, due to a transformation function T:

T(UKm) ---------> {CKn, X}

Up to now T can be presented as an interactive function between the system and the designer.

X can be the unforeseen or the implicit knowledge or set of knowledge required to integrate UKm or required when UKm is being integrated. If in certain situations X is empty {Ø}, then the UKm is a kind of unstructured complete knowledge which becomes certainty a controlled knowledge by using AI techniques (Miniton et al. 89).

Very few CAD systems can actually manipulate part of the unforeseen knowledge. This can be related on the one hand to the poorness of the knowledge acquisition tools used in CAD systems and on the other hand to the problem of managing a dynamic interactive man-machine system.

Implicit Knowledge

What is implicit knowledge ? It is the knowledge which is felt though it seems impossible to express it in a given context. This is the very situation in which one misses the suitable tools (models or examples) to explain and to formulate an action or an object.

Implicit knowledge is the knowledge that one claims to understand, see and even use, but of which it is unfortunately impossible to tell anything (describe or explain) at a given time or in a given situation. Otherwise in certain situations or circumstances the implicit knowledge (IK) can become explicit knowledge (EK) as follows:

FT(IKm,S,T, X) ------> (EKn)

with:

FT: transformation function depending on :

S : given situation ;

T : given time ;

X : set of other parameters (sociology, psychology, information level, etc.).

Up to now the main operator of this function is the knowledge engineer whose elementary operations could be presented as follows (see figure2) :

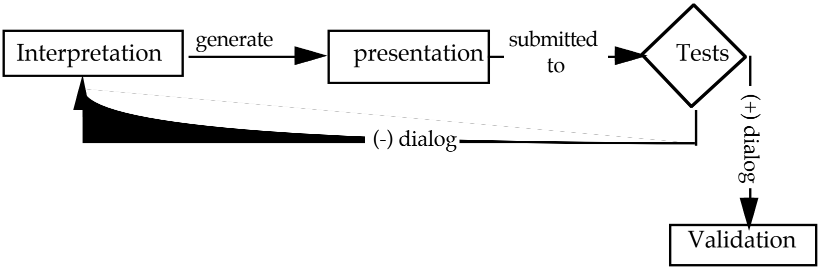


Figure 2. Knowledge engineer's elementary operations

The system, the operator and even the knowledge engineer must be aware of this kind of knowledge. They should wait and be ready to jump at the proper moment and in the right situation to find it out. It is nearly impossible to decide when and where the opportunity will arise. This is why an intelligent computer memory can be a good assistant.

N.B: If we accept this analysis we must admit that the certainty of both explicit and implicit knowledge can be always suspected.

A Professional taxonomy of knowledge in design : A Knowledge Engineer's point of view

At a different level the knowledge engineer uses other parameters to classify the knowledge involved in the design process. These parameters are more specialized than those described previously. He tries indeed to acquire as much information as possible by using several techniques (Hart 86) (dialogue with experts, documentation, experimentation, etc.) and at the same time he matches this information according to the state of the art in the CAD systems technology.

The main objective of the knowledge engineer is to improve the reliability of a CAD system in the design domain. He often begins by selecting parts of the knowledge which can be modelled and he cuts off the rest. Then he chooses the system which seems the most adapted to the resulting knowledge base (KB) then he starts again to adapt the knowledge base to the chosen system and so on (see figure 3).

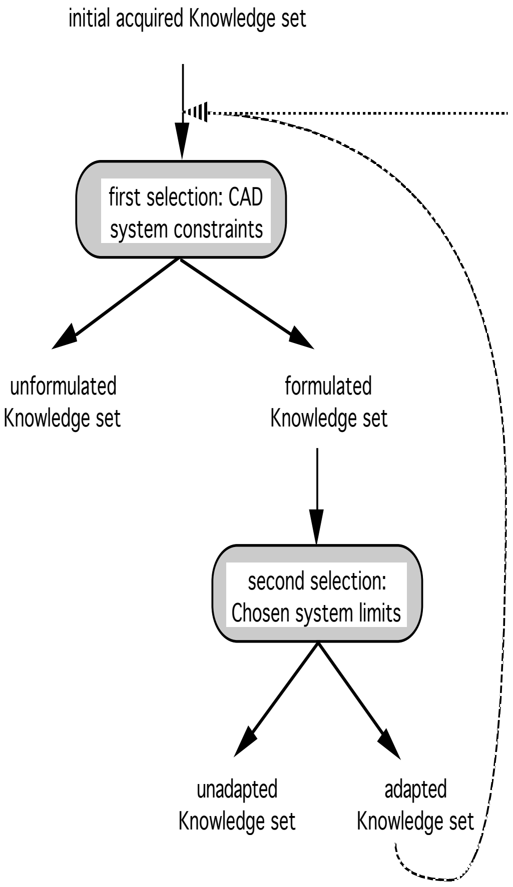

initial acquired Knowledge set
first selection: CAD system constraints
unformulated Knowledge set
formulated Knowledge set
second selection: Chosen system limits
unadapted Knowledge set
adapted Knowledge set

Figure 3. The knowledge selection process.

To throw light upon this idea, let us consider the problem of the architectural design where the knowledge engineer distinguishes and faces: the controlled general knowledge, the uncontrolled general knowledge, the specialized knowledge, the subjective knowledge and the unknown knowledge.

The Controlled General Knowledge (CGK)

The general knowledge in our example is the set of geometrical, technical and economical calculations, urban regulations, planning programs, etc. The controlled general knowledge is the explicit part of the general knowledge which is clearly represented and located. It consists of the formulated, published and taught knowledge. It could be manipulated by non-specialists. Generally most of this knowledge is nearly certain.

According to the artificial intelligence vocabulary, the controlled general knowledge can be defined as the part of knowledge for which the meta-knowledge is well known (i.e. when, where and how this knowledge must be used).

Let us consider the instance T and the situation S in which {G} is the set of general knowledge and {M} is the set of corresponding meta-knowledge. We can therefore define the set of controlled general knowledge {C} as follows :

it is an application Δ (T,S) of {M} on {G}:
□T and □S, Δ(T,S): {M, G} ----> {C}, where {C}   {G}, that is
[□ c □ {C}, □ m □ {M} by which Δ(T,S):{M, G} ---> c]

The Uncontrolled General Knowledge (UGK)

This is the set of general knowledge which does not always have enough corresponding meta-knowledge for every situation. In other words it is the set of elements which belongs to the set of general knowledge and does not belong to the set of controlled general knowledge.

Let us consider {U} as the set of uncontrolled general knowledge, so we can represent it as follows : for the instance T0 in the situation S0
[□ u □ {U}, ¬□ m Œ {M} by which Δ(T0,S0):{M, G} ---> u],
or
u □ {U} if u □ {G} and u □ {C}
{U} = {G} - {C}.

The Specialized Knowledge (SPK)

This is the set of the knowledge acquired by practice. The designer often faces in his practice different situations containing new constraints never manipulated before. In this case the designer generally solves his problem by analogy with other similar situations. So the specialized knowledge is a kind of experience consisting of the set of knowledge which allows one to deal with different situations.

In fact each designer stresses differently this part of knowledge according to his personal history, his degree of competence and his cultural background.

The specialized knowledge can be a simple knowledge, a set of knowledge or meta-knowledge.

At a given moment T0 and in a given situation S0 a specialized knowledge can become a controlled general knowledge at T1 or in S1 (with T1>T0 or S1 # S0). In fact it is perfectly natural that past and solid experiences should be transformed into general knowledge.

N.B.: experience proves that the specialized knowledge is not to be totally and automatically integrated into the controlled general knowledge ; only the part of knowledge frequently used in design practice is interesting to be taken into account.

The Subjective Knowledge (SUK)

This is the set of knowledge that the designer may use to face a new situation or constraints never met before. In another way it could be the set of knowledge related to creative or innovative activities. A general characteristic of the subjective knowledge is that it is too difficult to explain. It nearly has never been told, written or formulated. A new situation means that constraints and parameters have undergone some changes which do not allow to adopt traditional solutions. According to the importance of these changes, designers face the following situations:

- The case of a known new situation:

1. The designer can recognize the type of the situation by analogy with previous situations and he tries to adapt a new solution. Here he uses much subjective knowledge.
2. The designer cannot recognize the situation via a similar one. This means that the most thought of relevant parameters and characteristics used to recognize the situation have been changed or annulled. The problem in this case is to find, introduce, redefine or rather to create some new concepts which can be useful in order to recognize the situation. In this case the designer begins by using his subjective knowledge as a key to the other kinds of knowledge which could be concerned by this situation.

- The case of an unknown new situation :

1. The designer knows only about some constraints and some parameters concerning the situation. In order to give a solution the designer uses, in addition to his general knowledge, parts of his subjective and specialized knowledge. Therefore he investigates the set of given parameters and constraints to verify the reliability of his solution-plan.
2. The designer has the full responsibility and liberty to give a solution ; it means that there is no given critical data to limit the number of possible solutions. Sometimes the designer suggests or more precisely tries to apply a new idea or an unexpected philosophy which can help him start a solution-plan. At the beginning the designer uses only some general knowledge or meta-knowledge. This allows him to acquire a new knowledge corresponding to his idea or philosophy. This new knowledge resists if it is successful ; otherwise it will be annulled and the designer starts again. Therefore it can be supposed that in certain situations the designer uses meta-knowledge in order to generate a new knowledge ; so we can consider the subjective knowledge in this case as a kind of meta-knowledge.

Thus several questions concerning subjective knowledge could be raised :

- Should meta-knowledge be defined before the concerned knowledge itself ?
- Is there any rule or any parameter to control this process ?
- Should meta-knowledge and knowledge be conceptually separated ?
- When must these questions be taken into consideration ?
- Etc.

The Unknown (U)

It could be an answer to many questions which have been asked for a long time. The unknown has never been told, explained, formulated, modelled nor even directly felt. Managing the unknown is an important criteria in expert competence.

N.B. : This paper does not give any direct solution to these problems. But it claims the importance of adapting a very high level of dynamic man/machine dialog controlled by knowledge acquisition and learning techniques to be associated to a CAD system.

A practical taxonomy of knowledge in design : The designer's point of view

In a pragmatic approach we consider that the knowledge engineer must develop and integrate the basic set of design knowledge. Then the dialog between the designer and the system must insure the evolvement of the domain knowledge. So in order to define an adapted man/machine dialog we must take into consideration the user’s point of view which will be the principal future source of design knowledge.

In a design project the designer is somehow both the customer and the producer of knowledge. He manipulates several kinds of knowledge at different stages of his work ; therefore he is the user of the known part of design knowledge.

Explicitly designer works by means of actions (declared goals) and not directly by means of knowledge. This means that the designer chooses an action then uses part of his knowledge to achieve it. But sometimes he chooses indirectly an action in order to investigate a knowledge later on. For example an architect chooses a type of facade in order to use a special form of window. In this case the set of knowledge concerning this window is the discrete goal and the type of facade is the declared one (see figure 4) So in this paragraph we are interested only in declared goals and we do not deal with discrete ones whose acquisition and manipulation cannot yet be controlled.

In this context the designer can have a very special point of view about the taxonomy of the set of knowledge he uses.

Maybe it can be represented in figure-5 in which we can recognize three kinds of trained actions : the controlled, the uncontrolled and the implicit actions.

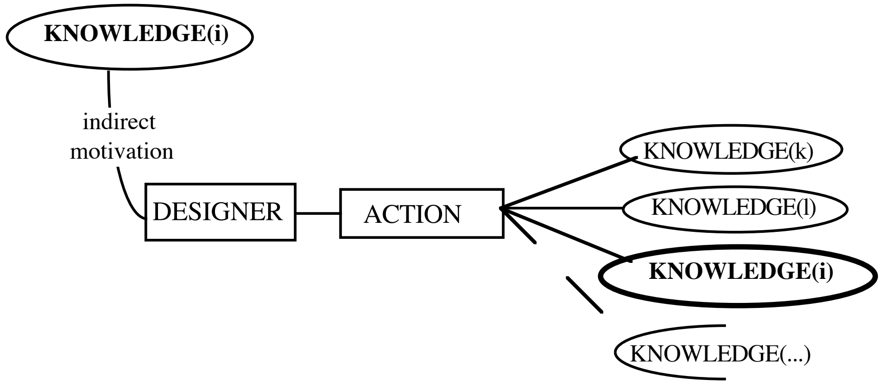


Figure 4. The designer’s discrete and declared goals

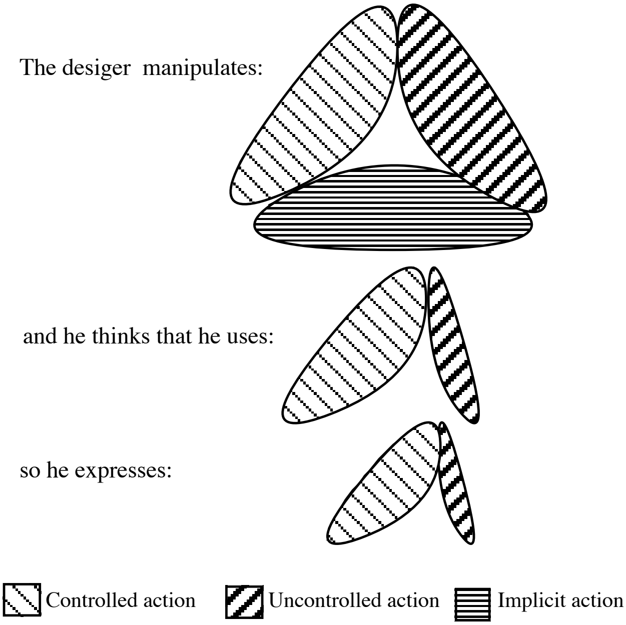


Figure 5. The designer's point of view

The Controlled Actions

It is the part of actions that the designer knows very well how to use, why and when. Controlled actions usually use controlled general knowledge. For example the designer knows that facades, spaces and walls must all be defined before he locates the windows.
Most traditional knowledge-based system techniques can manipulate this kind of action.

The Uncontrolled Actions

These actions are often made by the designer during the design process ; yet he cannot specify precisely in advance why, when and how to use them. For example every designer knows that he sometimes has to define the location of the sanitary equipments.
Knowledge engineers consider these actions as a set of uncontrolled general knowledge.
Acquiring this kind of action must be dynamic and requires advanced knowledge acquisition tools based on machine learning techniques (Zreik 89).

The Intuitive (or Implicit) Actions

An intuitive action expresses in fact the cleverness and the competence of the designer. It is usually implicit and sometimes the designer can feel it only a long time after he has used it, generally when he faces a similar situation. To define the shape of a facade for a private house for example is often an implicit action. Many architects usually explain their choice by the necessity to please their customer.

Taking this fact into account can lead to the understanding of the role which should be played by the knowledge engineer or by the knowledge acquisition tools (KAT) to model in order to manipulate the design knowledge's world.

A dynamic distribution of the Knowledge involved in the design process: A knowledge engineer's point of view

Let us consider the design domain as it has been previously defined. To improve the performance of the design model we have tried to classify the different types of knowledge involved in the design process according to their importance in a given project.

The figure-6 shows some examples of knowledge distributions corresponding to certain projects at their first stage of design process. The following cases have been chosen to throw light upon these distributions and their variations:

case 1: designing a traditional project for a council house construction in a known regular urban area. In this case the controlled and uncontrolled general knowledge represent the most important parts of the knowledge involved in the design process.

case 2: designing a new civil monument in urban area. Here there is not any controlled or uncontrolled general knowledge at the first stage of the design process ; only experience and subjective knowledge have to be relied on.

case 3: designing the shape and the location of a bay-windbw in a room. This action needs much subjective knowledge and some uncontrolled general knowledge in the advanced stages of design.

case 4: designing the installation of the heaters in a habitable space. The controlled general knowledge is the most important part of the knowledge used in this kind of application ; some specialized knowledge could be useful in difficult situations.

case 5: designing a private habitation project. Here the part of uncontrolled general knowledge is as important as the part of specialized knowledge and it is thought that the part of unknown knowledge is very important.

case 6: designing an elevator in a existing council house. This well defined application uses much controlled general knowledge, some uncontrolled general knowledge and very little specialized knowledge. In this case the part of unknown knowledge is relatively less important than in the other cases (see cases 2, 3, 4, 5, 7, 8).

case 7: designing the shape of a building facade. Much controlled general knowledge is not needed when designing a facade. What is rather needed is much more specialized knowledge. The part of unknown knowledge is still very important.

case 8: designing a door. In this application the design knowledge is equally distributed between controlled general knowledge, uncontrolled general knowledge, subjective knowledge and unknown knowledge. In this situation the use of specialized knowledge is not as efficient as in the other cases (see cases1, 2, 5, 6).

As he develops a knowledge-based system, the knowledge engineer always gives priority to the most available and common knowledge generally used in the domain.

In a design project it is not easy to determine which type of knowledge must be given the greater importance. This can be explained by the facts that on the one hand it is very rare to

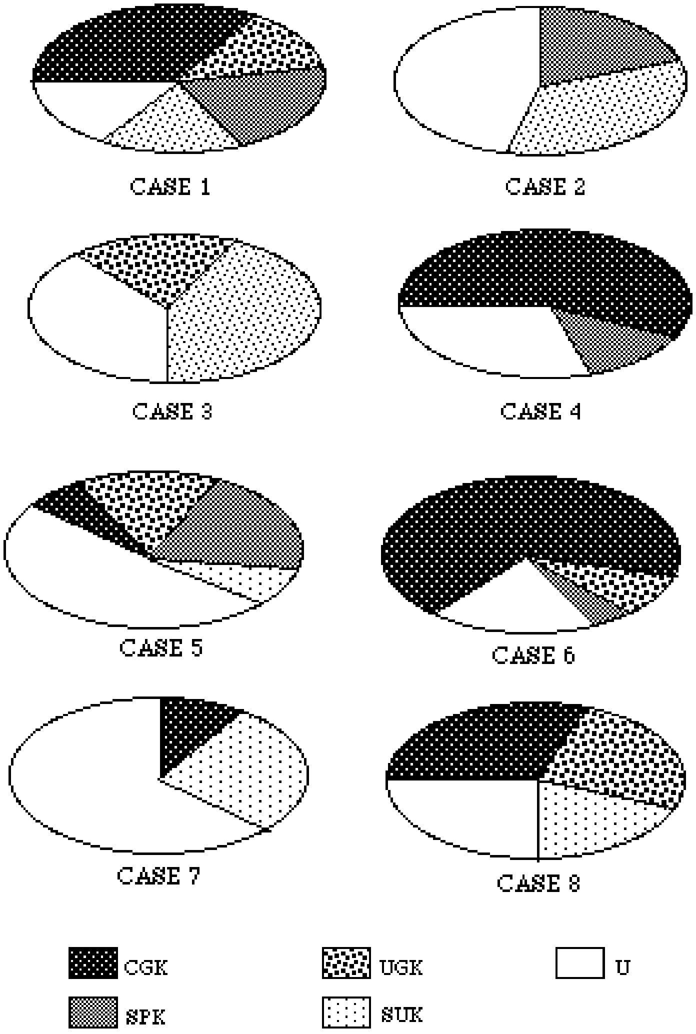


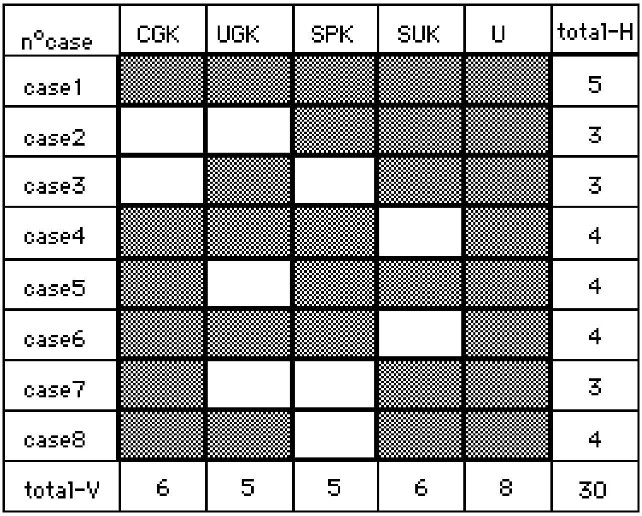
Figure 6. Design knowledge distribution considered by the knowledge engineer

realize two similar design projects and on the other hand the distribution of the different types of knowledge involved in the design process is variable ; there is no preliminary information about how it could or should be.

The figure-7 can help explain this problem. We can immediately understand that the importance of each type of knowledge varies from one application to the other. It is fairly easy to prove that for the same type of application, the distribution could be changed in different circumstances.

Design knowledge distribution is somewhat dynamic. We can even consider our knowledge about "knowledge distribution" as being undefined and uncontrolled.

It is remarkable that on the one hand the controlled general knowledge and the subjective knowledge are omnipresent and on the other hand the differences between the uncontrolled general knowledge and the specialized knowledge are negligible.



n°case	CGK	UGK	SPK	SUK	U	total-H
case1	▨	▨	▨	▨	▨	5
case2			▨	▨	▨	3
case3		▨		▨	▨	3
case4	▨	▨	▨		▨	4
case5	▨		▨	▨	▨	4
case6	▨	▨	▨		▨	4
case7	▨			▨	▨	3
case8	▨	▨		▨	▨	4
total-V	6	5	5	6	8	30

Figure 7. A boolean representation of design knowledge distributions.

At any rate we cannot deny the importance of the general knowledge (both controlled and uncontrolled) in so many domains of design.

In fact those types of knowledge have been already integrated in many applications by the use of several programming techniques (Mitchell et al. 85, Mostow 89).

Most of the obtained results are not very satisfactory because cases similar to cases number 2, 3, 5, 7 and even 8 are as often dealt with in architectural design as in other domains.

Therefore in certain situations (cf. cases 2, 3 and 5) it is not surprising that the general knowledge performances in the design process are not always sufficient to make CAD systems as useful as they should be.

Using Artificial Intelligence to improve the integration of the knowledge involved in the design process

Two different approaches are to be distinguished today when we speak about AI. First *the programming approach*: : this refers to all available AI techniques and facilities used to help develop applications in varied domains. Then *the research approach*: : it concerns the AI science which aims to improve the performances of computer reasoning.

AI Programming Techniques Approach in CAD Systems

AI tools have generally offered intelligent programming languages which have allowed non-programmers to prototype their own applications more rapidly.

AI programming techniques have brought a new dimension to the man/machine dialog in offering a simpler and unconventional language (nearer to the user's natural language).
It is considered that the user possesses already some knowledge to transfer ; yet the available conventional language is not sufficiently adapted to help this user formulate all his known knowledge nor his reasoning manner.

At the same time the use of AI techniques implies the help of knowledge engineers in critical cases. The knowledge engineer is very useful in such cases when the user finds it difficult to express and formulate directly his knowledge. Once knowledge is ready the knowledge engineer remains useful to model and transfer it precisely to programmers. Today in the development of particular cases the knowledge engineer encourages the user to give most of his knowledge.

Most of the time the greatest part of the knowledge acquired by knowledge engineers is controlled general knowledge ; according to the chosen programming environment, one can wonder about acquiring other types of knowledge. As we have already mentioned it various AI tools can integrate some uncontrolled general knowledge.

Most AI project development actors mix specified knowledge with subjective knowledge which they often include in the uncontrolled general knowledge. It seems too early to evaluate the importance of AI programming techniques to be able to integrate all types of knowledge involved in the design process in CAD systems.

In a specific design domain using much general knowledge AI programming techniques have proved their utility ; for example high-rise design (Maher 85), computer systems configuration (Dermott 82) and mechanical design (Brown et al. 88).

Finally using AI programming techniques has taught us that human intelligence is still to be investigated and particularly in regard to the building of intelligent systems.

AI science approach in CAD systems

Let us consider now that AI techniques allow us to integrate satisfactorily only a great part of the controlled general knowledge and part of the uncontrolled general knowledge.
In this context the objective of AI science is therefore to enable computers to integrate the other kind of knowledge involved in the design process ; it is also to increase and enhance continuously the quantity and the quality of integrated knowledge in CAD systems.

No doubt the integration of good knowledge acquisition paradigms using adapted learning apprentice systems (Mitchell et al. 85) in a CAD system environment will remarkably increase the quantity and enhance the quality of design knowledge-bases.

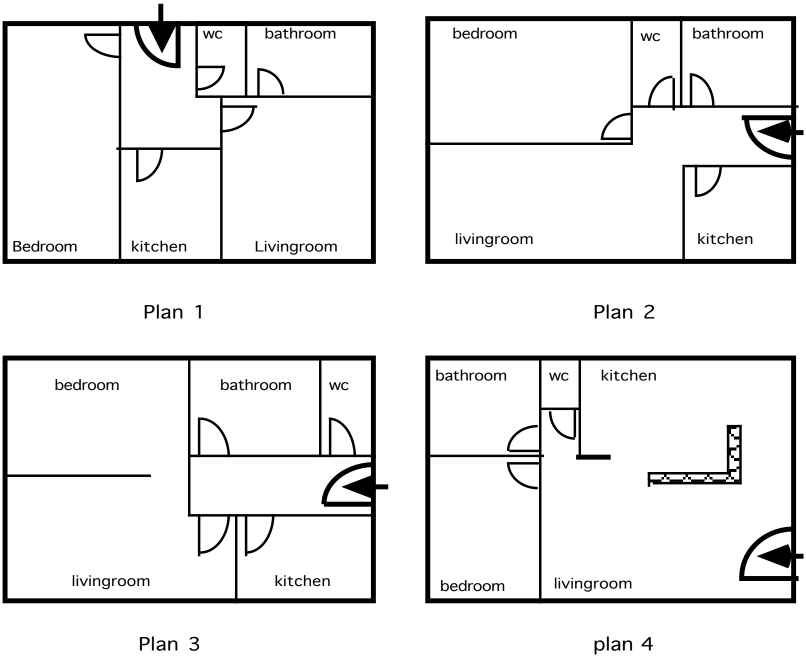
We have seen previously that uncontrolled general knowledge can become a controlled general knowledge by the addition of new meta-knowledge ; this can be done through the learning of problem solving strategy heuristics (Mitchell et al. 84).
In a particular situation such as case n° 2 (see figure-6) for example the designer uses only specialized knowledge and subjective knowledge. Then in order to make the CAD system useful it is necessary to endow it with the ability to learn. This could be achieved by the use of the techniques of explanation based learning (Miniton et al. 89), learning by analogy (Mostow 89) or learning from success and failure (Laird and Rosenbloom 86).

Is the use of these methods as easy as it seems ? Naturally the answer is no. We cannot yet acquire or learn the different types of knowledge in using any of these methods. Consequently we must:
- determine the different types of knowledge involved in our problem in order to choose the most adapted learning concepts and tools. As design activity is not repetitive we can privilege a very interactive system associated with a learning apprentice system (Tecuci 88).
- use an incremental learning system based essentially on the principles of learning by analogy (Carbonell 86) and learning from examples (Dietterich et al. 84).
- admit that system users must be specialists in their domains.
- consider that a new knowledge is learnt when the following tasks have been achieved :
1. Acquiring a new knowledge = transfering it from the expert to the system ;
2. Generalizing the acquired knowledge = transforming it into a general knowledge having semantics links with the other elements of the knowledge bases (Kodratoff et al. 86).
3. Validation of generalization = improving the new general knowledge by using the techniques of seeking similarity and an Intelligent Man/Machine Dialog (Guena et al. 1989).
So we can summarize the knowledge learning process as follows :
knowledge learning = knowledge acquiring + knowledge integrating (generalization + improvement).

Could AI help to select the good knowledge to be learnt ?

In fact this is the most important problem in design. In the first part of this paper we have suggested a classification of the knowledge involved in the design process. Then we have tried to locate the help of both AI techniques tools and theoretical methods in order to learn a new knowledge without any selection criteria concerning the nature and the importance of this knowledge.
The learning process is both dynamic and selective. In the design process a static hierarchy of knowledge, according to its qualitative or quantitative importance in the design project, does not exist.
Let us consider for example the plan 1 (see figure 8) ; it bears much information on the architectural knowledge. It is not easy to recognize and select immediately the different types of manipulated knowledge, even the one that must be learnt.
But if we observe all the plans on figure 6 and if we try to find out where the differences lie or what the plans of this set have in common, we shall rapidly make out some ideas about them : those are the plans of flats ; their surfaces are the same, they have a living-room, a bathroom, etc.

So by introducing machine learning techniques such as learning from examples (Quinlan, 89), learning by analogy (Mostow 89) (Winston, 80) or explanation based learning (Dejong 86) (Schank et al. 89) AI could assist designers to find out some new concepts. But in order to obtain good results the knowledge engineer, the designer and the programmer must at once choose the most adapted methods to their applications and define an available model of knowledge representation corresponding to architectural design knowledge. Works carried on in this domain are very important (Akin 88), (Fleming 88), (Radford et al. 85), etc.



Plan 1

Plan 2

Plan 3

plan 4

Figure 8. Set of architectural plans

Conclusions

As a matter of fact what has been indirectly attempted in this paper is to grasp the nature of the knowledge involved in the design process. On the other hand we have tried to demonstrate that integrating all kinds of knowledge within a system is complex, not always necessary and non mastered yet.

We have suggested the use of AI tools such as machine learning techniques. This can be one element to model a really interactive design system in a set of limited possibilities.

Today AI techniques are very useful in several types of applications. But if the performances of certain systems are sometimes not satisfactory, then the AI techniques alone must not be held as responsible. The complexity of the knowledge domain in design is not to be overlooked.

Today the large variety of available technologies must enable to improve the quality of design systems to insure a high level of interactivity.

References

Akin O. , 1988, Expertise of the Architect, in Expert Systems for Engineering Design, ed. by Michael D. Rychener 173-192, Academic Press edition, Pittsburgh, Pennsylvania.

Brown D. C., Chandrasekaran B., 1988, Expert System for a Class of Mechanical Design Activity, in Expert Systems in Engineering, ed. by D. T. PHAM, 334-360, IFS Publications/Springer-Verlag.

Carbonell. J.G. , 1986, Derivational Analogy : a Theory of Reconstructive Problem Solving and Expertise Acquisition. In R.S. Michalsky, J.G. Carbonell, T.M. Mitchell Eds, Machine Learning : An Artificial Intelligence Approach Vol 2. Los Altos, CA : Morgan Kaufmann.

DeJong G. F., 1986, Some Thoughts on the Present and Future of Explanation-Based Learning, in R.S. Michalsky, J.G. Carbonell, T.M. Mitchell Eds, Machine Learning : An Artificial Intelligence Approach, Vol. 2. Los Altos, CA : Morgan Kaufmann, pp.571-590.

Mc Dermott J., 1982 , “R1: Rule-Based Configurer of Computer Systems”, in Artificial Intelligence, vol. 19, n° 1, 1982.

Dietterich T.G., Michalski R.S., 1984, A Comparative Review of Selected Methods for Learning from Examples, Machine Learning an AI approach, Springer-Verlag Edition, 41-75.

Fleming U., 1988, Rule-Based Systems in Computer Aided Architectural Design, in Expert Systems for Engineering Design, ed. by Michael D., Rychener, 93-110, Academic Press edition, Pittsburgh, Pennsylvania.

Guéna F. , Zreik K., 1989, An architect Assisted Architectural Design System. AIENG 89, Cambridge, UK 10-13 July 1989.

Hart A., 1986, Knowledge Acquisition for Expert System. Chapter 4, pp. 39-48. Kogan Page Ltd- U.K

Heath T., 1989, Social Aspects of Creativity and their Impact on Creativity Modeling”, Preprints of International Round-Table Conference, Modeling Creativity and Knowledge-Based, Creative Design, 11-14 December, Heron Island , 1989, pp. 1-12.

Kodratoff Y., Ganascia J.G. , 1986, Improving the Generalization Step in Learning, R.S. Michalsky, J.G Carbonell, T.M. Mitchell Eds. Machine Learning : An artificial Intelligence Approach, Vol. 2. Los Altos, CA : Morgan Kaufmann.

Laird J.E., Rosenbloom P.S., Newell A., 1986, Chanking in SOAR : The Anatomy of a General Learning Mechanism, Machine Learning n° 1, 1986, 11-46.

Maher M.L., 1985, “Hi-Rise and beyond : Directions for Expert Systems in Design”. In CAD vol. 17, number 9, Nov. 1985, published by Butterworths, pp. 420-427.

Miniton S., Carbonell J.G., Knoblock C.A., Kuokka D.R., Etzioni O., Gil Y., 1989, Explanation-Based Learning : a Problem Solving Perspective, Artificial Intelligence vol. 40, n°1-3, Sep. 1989, 63-118.

Mitchell T.M., Mahadevan S., Steinberg L.I., 1985, “Machine Learning, a Guide to Current Research”, Kluwer Academic Publishers, pp. 203-207.

Mitchell T. M., Utgoff P.E., Banerji R., 1984, “Learning by Experimentation : Acquiring and Refining Problem Solving Heuristics” in Machine Learning an AI Approach, Springer-Verlag Edition, 163-189.

Mostow J., 1989, “Design by Derivational Analogy : Issues in the Automated Replay of Design Plans” in Artificial Intelligence, vol. 40, n°1-3, Sep. 1989, pp. 119-184.

Quinlan J.R. “Induction from Structured Data” in Australasian Conference on Expert Systems in Engineering, Architecture and Construction, 6-8 Dec. 1989, pp. 303-320.

Radford A. D., Gero J.S., 1985, “Towards Generative Expert Systems for Architectural Detailing” in CAD vol 17 number 9, Nov. 1985, published by Butterworths, pp. 428-434.

Schank R.C., Leak D.B., 1989 , “Creativity and Learning in a Case Based Explainer” in Artificial Intelligence vol. 40, n°1-3, Sep. 1989, pp. 353-386.

Tecuci G., 1988, “DISCIPLE : A Theory, Methodology and System for Learning Expert Knowledge”. Thèse de doctorat, Université de Paris-Sud, Centre d'Orsay, 1988.

Winston P., 1980, “Learning and Reasoning by Analogy”. Common ACM 23 12, 1980, pp. 689-703.

Zeisel J., 1981, “Inquiry by design : Tools for Environmental Behavior”. Research, Brooks-Cole, Monterey, California, 1981.

Zreik K., 1989, “Using Learning Apprentice System in Construction” in Australasian Conference on Expert Systems in Engineering, Architecture and Construction, 6-8 Dec. 1989, pp. 339-358.