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## REFLECTIONS

# Intelligent computer-aided design systems: Past 20 years and future 20 years

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## 1. INTRODUCTION

### 1.1. Intelligent computer-aided design (CAD): First 20 Years

Triggered by expert systems technology, artificial intelligence (AI) was a silver bullet in the early 1980s. AI seemed to be able to perfectly solve various problems that involved any intellectual activities. For instance, MYCIN (Shortliffe, 1976), developed at Stanford, gave a strong impression that medical doctors could have been soon supported by a clever consultation system, resulting in more accurate diagnoses. Inspired by these, also in engineering fields, a variety of experimental systems for fault diagnosis, planning, selection, and design were developed, which demonstrated promising possibilities of their applications.

In 1983 I coined the term intelligent CAD, which had been called expert CAD or knowledge-based CAD until then (Tomiyaama & Yoshikawa, 1983). An epoch-making event was a conference organized by IFIP Working Group 5.2 in 1984, entitled *Knowledge Engineering in CAD* (Gero, 1985), at which many (mostly non-US) researchers active at that time presented their systems. In 1987 Working Group 5.2 organized a follow-up conference entitled *Expert Systems in CAD* (Gero, 1987). Following these, Eurographics organized a series of workshops between 1987 and 1990 (ten Hagen & Tomiyama, 1987; Akman et al., 1989; Barthès, 1990; ten Hagen & Veerkamp, 1991) and IFIP Work Group 5.2 ran workshops between 1987 and 1991 (Yoshikawa & Gossard, 1989; Yoshikawa & Holden, 1990; Yoshikawa & Arbab, 1991).

At the beginning, the goal of intelligent CAD development was to develop a CAD system that could design products more or less automatically with minimum user inputs

and interactions. Here, design meant many things; from analysis, selection (of components or materials), parametric design, optimization, data integrity management (such as geometric constraint management), process planning, and synthesis. Many knowledge-based systems were developed for a rather focused application, exhibiting a variety of “intelligent” design behaviors. These systems were used in practice, and some of them actually could successfully achieve what was expected, namely (partial) automation of design but mostly in parametric design and selection type tasks with constraint management. Synthesis type applications remained largely unsolved.

However, they soon revealed many problems. First, obviously those systems were not design systems for creative design. These systems could only present design solutions prescribed and embedded in the knowledge base. In other words, they could not be used to design for new products but more for “routine design” and “redesign,” although industrially perhaps 95% of design cases were such routine design or redesign (parametric design). If the system could not handle a small portion of design that required new design, the whole system was often perceived as a failure, which is especially the case for oversold concepts such as AI.

Second, these systems typically focused on a small domain, sometimes even a too small domain, which required only a dedicated model to describe design processes. The lack of generality in the design process model prevented them from being applied to design in other domains. In contrast, we did not and still do not have a general framework to model and describe design, perhaps because research in design theory and methodology was premature. Even today, scientific understanding of design, that is generic and universal, is yet to be established.

Third, the maintenance of the knowledge base soon became a big problem. Product design changes day to day. Component design also advances day by day. If the system cannot cope with such advances quickly and in a timely manner, the system becomes obsolete very quickly. The

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knowledge base had to be maintained, but this was extremely difficult or even nearly impossible.

Fourth, the system had very little connection or lacked integration with existing CAD systems (such as a geometric modeling system for mechanical design). This meant that intelligent CAD should have been developed as part of a product development environment, which commercial developers were targeting, rather than as independent stand-alone systems.

To overcome these problems, and in particular to tackle synthesis type tasks, it was attempted to develop a large-scale knowledge base containing a variety of engineering knowledge and model-based reasoning techniques using qualitative physics. However, I must say that most of them still turned out insufficient to build a CAD system that could really solve synthesis type tasks (or creative design problems). Reflecting these, there appeared even a criticism that intelligent CAD was impossible to develop but existed only as a vision (MacCallum, 1990).

Meanwhile (particularly in the early 1990s), the research focus shifted toward more practical approaches, rather than tackling those “missions impossible.” Good examples of such practical approaches are Design for X approaches that looked at tools to arrive at better manufacturability, for instance. Many advice systems were developed that could suggest better design solutions for easy manufacturing, using a simple rule-based system combined with a geometric modeling system. From the viewpoint of AI techniques, there is nothing fancy about these systems, but all in all they demonstrated that it is not the reasoning method that does the job but the knowledge. Combined with the concurrent engineering boom from the late 1980s, this trend dominated the research field.

At about the same time, the AI computing paradigm also shifted from classical symbolic computing to soft computing such as fuzzy logic, artificial neural networks, genetic computing, and simulated annealing. Original intelligent CAD concepts were mostly based on the classical symbolic computing paradigm. Some of those soft computing based systems did exhibit even some synthesis capabilities (i.e., generating solutions that are not prescribed in the knowledge base), but perhaps their biggest advantage was that they required less precise inputs (you begin with a rough estimate but the system can guide to arrive at more optimal solutions). These systems, based on soft computing techniques, were implemented mostly for a variety of design tasks such as selection, optimization, and synthesis.

In the middle of the 1990s, the goal of the intelligent CAD research added a new perspective: to develop an integrated design support environment that can provide useful knowledge with designers based on design knowledge and manage design information and knowledge (Tomiyama et al., 1996; Mäntylä et al., 1997; Finger et al., 1999). In contrast, many commercial CAD platforms were aimed in the same direction, further addressing such issues as product model

definition and management, collaboration support, and data and knowledge integration, inspired largely by a global trend of knowledge management. Of course, a good subject of discussion is whether to develop an intelligent element within such an existing platform (such as a geometric modeling-based integrated CAD system) or to develop a totally new platform based on the concepts of intelligent CAD. However, for practical reasons the former has more obvious advantages than disadvantages.

## 1.2. Intelligent CAD: Next 20 years

The goal of intelligent CAD to automate design was almost a mission impossible, and the dream of intelligent CAD as a system started to die already perhaps in the middle of the 1990s, although I strongly believe that the concepts are still valid and still exist as a vision for a number of reasons.

There are two major concepts of intelligent CAD. One is related to the original goal of intelligent CAD, which is the intensive use of design knowledge to design artifacts in one way or another. The other is related to the second goal, which is that intelligent CAD should exhibit knowledge management capabilities because design is mostly a knowledge generation process. These two concepts were gradually incorporated into commercial CAD platforms over the last 20 years. For example, knowledge representation in the form of rules is now a standard feature of such systems. Constraint management based on constraint solving techniques is another example. Technologies developed in the intelligent CAD period are now lending themselves as a whole to knowledge management features.

However, it might still be useful to discuss what future research should look like, because intelligent CAD still exists as a vision, and because there are new opportunities due to the technological and theoretical developments. Perhaps we are now equipped with a set of better theories, methodologies, and tools to handle design knowledge. For example, advances of the Internet technologies now enable us to think about building a collectively created very large-scale knowledge base as an integration of distributed dedicated knowledge bases that contain a variety of engineering design knowledge. Ontology technologies are a promising approach to modeling engineering design knowledge and to facilitating knowledge sharing and reuse among different participants, although there remain research issues yet to be investigated.

Design process models were another missing element from the intelligent CAD, but this has made significant advances over the last 20 years. For instance, research in concurrent engineering has yielded a significant amount of understanding about actual product development processes. Design process modeling and management techniques are now available to develop a design process control mechanism.

However, we should be careful about the context in which intelligent CAD is discussed. Twenty years ago industry was primarily addressing such issues as cost and quality.

Now we also need to address, for example, product development speed (in terms of both time to market and time to deliver), liability, and life cycle issues. Products as well as product development processes have become significantly more complex, reflecting not only product complexity but also multiple stakeholders in the process. Because of this, we are not facing the same problem, although how it is phrased is the same: how can we tackle and reduce the complexity of product development?

## 2. EPILOG

When I was a PhD student 20 years ago, a group of PhD students had a chat with one of professors of the department, probably while drinking beer. The subject was about the lifetime of research topics. If your research topic is something that can be solved within a very short period, it would not be a good subject for a PhD thesis. On the contrary, if it would take too long despite the research effort we expend, perhaps it is something uninteresting or even too difficult for a PhD student. Thus, the professor started to comment very frankly on what he thought about each of our subjects. After half-jokingly making comments on topics of other students, he then looked at me and said, “Mr. Tomiyama, yours cannot be solved even in 20 years.” However, he also added, “You don’t need to worry, because you won’t be unemployed.”

I have to agree with his comments. A “mission impossible” research subject is perhaps too much for a PhD research dissertation, but it is valuable for a research community as

a whole. If I am correct, it is time for our research community to seriously think about our collective effort.

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