3th International Conference on Public Communication of Science and Technology (PCST), Montreal,Canada,10-13 April,1994

CULTURAL DIFFERENCES IN RESEARCH ON NEW TECHNOLOGIES: A CASE STUDY ON THE HISTORICAL DEVELOPMENT OF CAD RESEARCH AT UNIVERSITIES IN THE USA, FRANCE AND GERMANY

Irmela Gorges, Professor of Sociology
FHVR – Berlin, Germany

Introduction

An international comparison on the characteristics, i.e., the “culture” of research and development of new technologies can help to evaluate the adequacy of comprehensive research methods and serve as a starting point for critical discussions on future developments of new technologies.

In this paper, research on the development of new technologies is discussed at the example of Computer Aided Design Systems developed at universities in the USA, France and Germany. The three countries were chosen because CAD systems were first invented and developed in the USA and transferred and adapted to the specific conditions in Germany after basic research had been completed, whereas in France similar research commenced at about the same time as in the USA but led to clearly different characteristics of CAD investigations and CAD systems as in the two other countries.

Characteristics of research on CAD systems in the USA: 1955-1985

In the USA, university research into systems now known as CAD systems started at the Massachusetts Institute of Technology (MIT) in Cambridge. Since the end of the Second World War, MIT had been engaging in research which later developed into CAD research around the mid-fifties. Up to the mid-sixties, both this preparatory work and the actual CAD research was wholly or largely financed by the American Defence Ministry and here, in turn, mainly by the Navy and the Air Force.

CAD systems at MIT, of course, could not have been developed without prepatory work in computer hardware and software. Both research fields had been developed at MIT since the early 1940s. At the beginning of the Second World War, the Servomechanisms Laboratory was established at MIT for the purpose of examining control processes. One of the research projects started at this laboratory in 1944 examined the possible development of flight simulators. Jay W. Forrester, head of the project, and his close colleague Robert R. Everett, after they had informed themselves about ongoing research on analogue and digital computers at the time, decided to build a computer to process the necessary mathematical operations for the flight computer. Their research group spent about 10 years to build the computer. At the beginning of the 1950s, following the first nuclear tests by the USSR in 1949, the Korean War in June 1950 and the start of the Cold War, the project was given more attention, and by 1954 the result could be employed as a reliable computer for general purposes. "Whirlwind", the name that was given to the computer due to its high processing speed (Redmont, Smith, 1980), worked with vacuum tubes and was equipped with a 30-cm diameter radar screen, which was originally intended for the graphic representation of the calculated flight path of missiles, and a light pen which was originally called "light gun".

After Whirlwind was finished, members of the research group who had built the computer decisively influenced the development of high-speed computers in the USA. For instance, Kenneth Olsen who took part in the Whirlwind project as a graduate student, became the founder of the Digital Equipment Coporation (DEC). DEC soon built faster computers which replaced Whirlwind. The TX-0, then the TX-2 was given to MIT's Lincoln Laboratory, which had been established several miles away from the MIT campus where exclusively military research was being conducted while Whirlwind was still used by students from other disciplines on the MIT campus. Olsen's undergraduate roomate, Robert W. Mann, with whom he had often discussed possible applications for digital computers, became head of the Design Division at MIT's Mechanical Engineering Department at the end of the fifties. In this position, he was able to decisively exercise an influence on the future development of CAD systems at MIT in the 1960s .

But even if the hardware development of computers at MIT for military purposes preconditioned effective research on CAD systems, research on the utilization of computers for the design process was a continuation of software developments at MIT, again for military purposes. In the fifties, the Servomechanisms Laboratory of the Electrical Engineering Department carried out studies on the development of computer programs for the numerical control of machine tools. Already in 1950, Alfred Süsskind, using research funds provided by the Parsons machine tool factory in Michigan, had used Whirlwind to calculate the motion paths of lathes. Following the start of the Cold War, the Air Force showed an interest in these studies. When J. Francis Reintjes (Reintjes, 1991) became head of the "Servo Lab" in 1952, he continued the studies on improving the control of machine tools. In 1955, under his guidance, John H. Runyon wrote "subroutines", i.e., part instructions for machine tools and, in the same year, Arnold Siegel presented the first programming of numerically controlled machine tools on Whirlwind; this, however, was limited to the motion paths of two-dimensional surfaces and could not be transferred to three-dimensional tasks. In 1956, therefore, Ward, the former head of the Servo Lab, together with Reintjes, decided to use the remaining funds from a project financed by the Air Force, the Digital Flight Test Instrumentation Project (DFTI), for further developments of Siegel's studies for three-dimensional tasks. Douglas T. Ross, a mathematician who had been working successfully on the DFTI project under the leadership of John Ward since 1952, was appointed head of the newly created "Computer Applications Group"[1]. The intention of this group was to work out a program enabling engineers to carry out the programming of three-dimensional motion paths for machine tools in easy-to-learn commands. By December 1956, the Computer Applications Group, under Ross, had introduced a concept for three program parts (one based on the description of paths using nodes, one using curves and one using "regions" (surfaces)). The hierarchic construction of each individual part made it possible, by means of just a few input commands, to evoke a series of further operations required for controlling the motion paths of machine tools. Later on, this "automatic" programming was called "Automatically Programmed Tools" (APT) (Ross, 1989). In 1957, on Ross's request, programmers from the "Subcommittee on Numerical Control" (SNC) of the Aircraft Industries Association (AIA) and the machine tool industry came to MIT for a few days in order to complete APT. They succeeded in writing the program,

---

1. In 1956, the group consisted of two scientists and two students.

except for the solution of one problem. It remained unclear as to how to determine whether a node was located inside or outside of the workpiece. According to Dwight Baumann, a doctoral candidate and instructor in the design division of the Mechanical Engineering Department, Ross managed to solve this problem on the weekend following the meeting with the aid of a textbook published back in 1947 (Olmsted, 1947) that Baumann had recommended to him. Further research on APT, the test phase and error elimination, took another two years and it was not until 1959 that APT was presented to the public at a press conference. The program, which was installed on Whirlwind, showed the motion path of a machine tool in the production of an ashtray. Further development and updating of APT, which still had to be adjusted to the respective types of machines and tools before it could be used in industry, were transferred to the Illinois Institute of Technology Research (IITRI)[2].

Already before the small amount of funds allocated for the APT project ran out, the Computer Applications Group had considered the possibility of extending automation research to other stages of the production process[3]. Early in 1959, the group met with representatives of the design division of the Mechanical Engineering Department, among them, Robert W. Mann, Steven A. Coons and Dwight Baumann. They decided to discuss any studies on the applications of automatic programming for the design process in a series of tutorials. It is claimed that the notion “Computer-Aided Design” and the acronym CAD was coined in the course of these discussions. Finally, it was decided to apply to the Air Force for research funding for a common CAD project. However, when the work on the project started in 1959, both groups followed their own research approach. The former APT developers around Ross extended APT by a compiler (language translator) and additional part programs. Again, more than 30 programmers from more than 20 companies were invited to MIT for 17 months in order to achieve this. In the mid-sixties, Ross introduced the AED (Automated Engineering Design or Algol Extended for Design) program, which he considered to be the beginning of the philosophy of complex programming (Ross, 1989). In doing so, he integrated

---

2. The former Armour Research Foundation.

3. It is claimed that the representative of the Air Force responsible for MIT referred Ross to an article on the development of a “drawing machine” in 1957 (Ross, 1989: 7).

the design process into the programming of complex tasks which were regarded as a problem solution, and to which he gave the artificial name "Plex".

As opposed to this, the members of the Design Division of the Mechanical Engineering Department under Robert W. Mann directed their attention towards a more pragmatic analysis of the design process. They considered the most important research aims to be the development of input commands for the processing of graphic data, the processing of these data for fabrication needs, and the output of the same data on VDUs or on drafting machines (Mann, 1992). Under the guidance of Coons, Mann and Baumann, several master's theses were written on these topics. A doctoral dissertation written by Ivan E. Sutherland, a Ph D candidate in electronic engineering[4], was considered the most important point of departure for later research on CAD systems. At the Lincoln Laboratories, Sutherland developed a program named SKETCHPAD. The program, which was implemented on Olsen's TX-2, enabled a construction and modification of graphics on a vector screen with the aid of a light pen, and modifications and rotations of the constructed geometrical figures, as well as "stress analysis" – the bending of shapes to which pressure is applied, for example, bridges (Sutherland, 1963). Sutherland completed his study in 1963. Shortly after this, Timothy E. Johnson, in his master's thesis, extended the program from two-dimensional to three-dimensional graphic representations (Johnson, 1963). Although Sutherland was not a member of the design division, Mann and Coons gave their unqualified support to his study and considered the SKETCHPAD program to be a result of their own work within the CAD project.

The CAD project was finished in 1964. The Electronic Systems Laboratory took over subsequent studies at MIT until 1969 under the leadership of Reintjes. During this period, a larger graphic display unit, called Kludge, was developed, and the AED program was linked to a project called MAC[5], which had been running since 1963 and in which a central mainframe computer was employed in time-sharing

---

4. The dissertation leading to a Ph D degree was written under the guidance of Claude E. Shannon. Sutherland thanked Marvin Minski, Steven A. Coons and Douglas T. Ross for the support they gave him (Sutherland 1963: 1 onwards).

5. Machine-Aided Cognition or Multi Access Computer or Maximum Assembly of Components.

operation. The Mac project was financed by the Office of Naval Research, on behalf of the Department of Defense (DOD) and its "Advanced Research Projects Agency" (ARPA) department.

In keeping with MIT's view of technological research, it is normal practice to publish results without any restrictions and release them to further development for practical purposes. At the end of the sixties, researchers involved in the CAD project left MIT in order to translate the research results into commercial success as well. Douglas T. Ross founded the SofTech software company in 1969 in order to develop further and sell the AED program to both civilian and military concerns. Ivan Sutherland first went into military research[6], but returned to university research in 1966, first at Harvard, where he met Bob Sproull, and was later offered a position at the Computer Center of the University of Utah in Salt Lake City by David Evans where, together, they founded the software company Evans & Sutherland, which still exists. Today, Sutherland and Sproull work with the Sun Corporation. Steven A. Coons left MIT and first moved to Harvard University, and then became advisor to the Ford Motor Company, where he developed the concept of the "Coons patches" which were used for freely-shaped areas[7]. In addition, students who had become acquainted with the CAD project at MIT founded software companies, like Computer Vision, established by Philippe Villers, or Calma or Applicon. Others, who had taken part in tutorials held by Coons at MIT in the early sixties, became teachers of "CAD" at universities and in industry such as, for instance, Bertram Herzog, manager of the Engineering Methods department of the Ford Motor Company, or S.H. "Chace" Chasen, head of the research laboratory at Lockheed Company, Atlanta, or Carl Machover, who had presided over several hardware and software firms, such as Information Displays, when he started his own consulting firm in computer graphics, the Machover Associates Corporation, in 1976.

In the seventies, the research approach to CAD developed by Coons and Sutherland received a great deal of attention at universities. However, in order to

---

6. For a while he was with ARPA.

7. Coons went to the University of Syracuse, to Hungary to visit Josef Hatvany at the Automation Institute of the University of Budapest and finally was invited by Bertram Herzog to became advisor at the University of Colorado, where he died in 1979.

gain the interest of potential users, the newly founded software companies decided to insolate the SKETCHPAD system's ability to produce drawings, and they concentrated their R&D on "computer graphics", aiming at obtaining perfect on-screen representations of objects in numerous colours, tints and with shadow areas. Sutherland himself has remained faithful to this field until today. However, in the early seventies, the terms "CAD" and "computer graphics" still were synonymous. It was only until the mid-seventies when a new research line split investigations into CAD systems from computer graphics. Bruce Baumgart introduced, in his doctoral thesis, the principal ideas of a first program on the computer-internal representation of three-dimensional bodies (solid models) which had been developed by Ian Braid in Cambridge, England. Braid's system was named BUILD.

Baumgart's dissertation initiated a second wave of CAD research at universities in the USA. But even if a considerable percentage of the solid modeling projects had been financed by the military, a large part of the new research line was sponsored by the industry. However, similar to the investigations into CAD at MIT in the sixties, several research lines of solid modeling were developed. Richard Riesenfeld, Elane Cohen and Tom Lyche at the University of Utah, Salt Lake City, developed the Alpha One System, which was able to convert b-splines into polygons, thus enabling conversion of Sutherland's 2-D program into the 3-D models, thereby combining Sutherland's research approach with the Cambridge school in England. Herbert B. Voelcker and Aristides A. G. Requicha at the University of Rochester[8] were engaged in geometric modelling research which was primarily funded by the National Science Foundation. The Production Automation Project (APT), in the course of which they developed the PADL program, was production-oriented CAD research insofar as they assumed that volume models were needed for the automated transfer of data from the design to the manufacture of parts by machine-tool programs (Requicha, Voelcker, 1982). At other universities, researchers turned their attention to special problems regarding 3-D systems, tackling the problem from the design aspect, such as David C. Gossard at

---

8. The first research on three dimensional programs had begun already in the early 1970s. Today, Voelcker teaches at the University of Ithaka, and Requicha, at the University of Southern California in Los Angeles.

MIT and Dave C. Anderson at the Purdue University. In this context, Charles Eastman, an architect, also has to be mentioned, who envisaged the application of solid modeling systems in designing buildings. Eastman developed the BDS (Building Description System) and GLIDE (Graphical Language for Interactive Design) (Eastman, Bear, 1976).

Symptomatic of the division between the research field of computer graphics and solid modeling, and the first integration of design-oriented and production-oriented research approaches, at the beginning of the eighties, was the history of Michael Wozny's research laboratory. The Center for Interactive Computer Graphics at the Rensselaer Polytechnic Institute (RPI), Troy, New York[9], which he had founded in 1977, was renamed the Rensselaer Design Research Center in the eighties and, at the same time, research was shifted to the standardization and integration of Computer-Aided Design and Computer-Aided Manufacture systems (CAD/CAM) (RPI 1991). However, the projects of the Center were far in advance of their realization in the practical field (RPI 1991).

A well-known episode concerning research on the integration of formerly divided research lines is the disagreement in the mid-eighties among "Chuck" Eastmann, Fritz Prinz and Kevin Weiler at the Carnegie Mellon University, Pittsburg, Pennsylvania, on the necessity of "non-manifold data structures" to enable the conversion of nodes into curves and into volume element systems, thus providing a transfer of the data required in the design process to the production process. The integration of systems which were specialized in different application sectors and the recombination of these by the reorganization and conversion of the data was indeed characteristic of CAD/CAM research in the USA in the eighties, but also of the research carried out in the Federal Republic of Germany and in France.

Characteristics of CAD investigations in West Germany: 1965 through 1985

CAD research in the Federal Republic of Germany started at the time the CAD-project at MIT ended, in 1964/65. In the fifties and sixties, German engineers had already gathered information about the research carried out at American

---

9. One of several research centers promoted by the National Science Foundation and working in close cooperation with industry.

universities, but it was not until the mid-sixties that representatives of the scientific and industrial communities made mutual efforts to take over CAD research results from the USA and adapt these for use in industry.

First and foremost, four institutes of West German universities produced exceptional results in the development of CAD systems: the Werkzeugmaschinenlaboratorium (WZL) at the Rheinisch-Westfälische Technische Hochschule (RWTH) in Aix-La-Chapelle, the Institut für Werkzeugmaschinen und Fertigungslehre (IWF) at the Technische Universität (TU) in Berlin, the Lehrstuhl für Maschinenelemente und Konstruktionslehre (LMK) at the Ruhr University in Bochum and the Institut für Rechneranwendung in Planung und Konstruktion (RPK) at the University of Karlsruhe. All the various research areas involved in the USA were also represented in West German CAD/CAM research but, here, the production-oriented CAD research field, which had long been under-represented in the USA, clearly dominated over the "computer graphics" research as fostered by José Encarnacaos at the University of Darmstadt. Ecarnacaos' research in Germany, up to now, has still not gained the same recognition it has in the USA.

The first phase of CAD research at universities in the Federal Republic of Germany was initiated by the directors of the two oldest production-technology research laboratories: Herwart Opitz of the WZL at RWTH, Aix-La-Chapelle, founded in 1906 by Adolf Wallichs[10]; and Günter Spur, since 1965 director of the IWF at the TU Berlin, founded in 1904 by Gerhard Schlesinger. First research efforts were conducted by Opitz and Spur, together with Walter Simon, professor at the TU Berlin, and Gerhard Stute, University of Stuttgart, both now deceased. Already prior to 1965 they carried out a project for the development of a programming language for numerically controlled machine tools which was funded by the German Research Association (Deutsche Forschungsgemeinschaft – DFG). But, research efforts were multiplied when, within the framework of a colloquium held at the WZL in Aix-La-Chapelle in 1965 to discuss possible ways of reducing costs in the production of small series, the representatives of industry and science agreed to adapt the APT program, developed by Douglas T. Ross at MIT in the

10. Adolf Wallichs was the first person to translate F.W. Taylor's book "On the Art of Cutting Metal" into German.

USA, for the automatic programming of machine tools. However, as APT was restricted to the motion path control of machine tools, the program was to be extended by a "technological" program module in order to ensure its introduction and distribution in Europe in a standardized form. From 1965 to 1967, with the aid of a newly founded EXAPT association and affiliated bodies, assistants from mainly the WZL developed the EXAPT program (EXtended subset of APT), which was subsequently further developed and distributed not only in the Federal Republic of Germany, but, with appropriate adaptations, also in other European countries.

Parallel to the development of EXAPT, first studies on how the computer could be applied to the design engineering process were begun at the two production-technology research institutes, the WZL of the RWTH, Aix, and the IWF of the TU Berlin. At the WZL, the main objectives of these studies were to supplement the rationalization of production processes by introducing rationalization measures into the design process. Rolf Simon, a doctoral candidate at the WZL, and Dr. Walter Eversheim, were the first to publish theses on "computer-aided design" (Simon, 1968) under the guidance of Opitz. They had found out that the number of mechanical design engineers in Germany had increased considerably since the end of the fifties and that their work, to a great extent, involved the production of routine design drawings. These routine drawings could be executed by a computer program. Eversheim proved that rationalization of the design effort could be achieved by reducing the variety of parts to 15 categories in three levels (Eversheim, 1969). The basic geometric shapes of these could be used in computer programs, and, from these, basic shaped parts could be assembled in a variety of designs. This point of view contrasted with the common conception that machinery manufacturers would mainly produce new designs and not variations on designs. Under the leadership of the Opitz's four successors, who were appointed in 1972, whereby especially Walter Eversheim and Manfred Weck pursued the fields of computer-aided design and production planning, further doctoral research at the WZL followed the approach of rationalizing production processes by reducing the variety of parts. Since the seventies, medium-scale and small companies, especially in the Aix region, were able to benefit from this research.

The doctoral candidates under Günter Spur's guidance at the IWF of the TU Berlin developed a system concept which was under discussion at international conferences. They attempted to reduce the variety of parts in a manner which would not only result in a reduction of the variety of functions but would also facilitate work planning by introducing work procedures capable of standardization. At the IWF, first graphics were successfully implemented on a computer in 1972. Among other programs, the COMPAC (COMputer PArt Coding) 2-D program developed by Jürgen Kurth (Kurth, 1971) became one of the well-known programs developed at the IWF (Krause, 1976). To enable its wide distribution, it was modular in structure, consisting of a generally usable part for shape elements, and of further modules which had to be specially created for applications in specific companies.

As opposed to the research at the WZL and IWF, the doctoral candidates under the guidance of Hans Seifert at the LMK, founded at the University of Bochum in 1969, had concentrated on the development of a design logic theory and the computer assistance of the design process. Proceeding from an analysis of the smallest element of a design process (Herold, 1974), they developed the modular PROREN system for supporting first-of-a-kind designs, which was first demonstrated in 1974 (Bargele, 1978). But it was not until the mid-eighties that Seifert started to link the design logic system developed by him with the PROREN CAD system (Seifert, 1986/87).

Already in 1975, all three laboratories, the WZL, IWF and LMK, had caught up with the research standard of American CAD research. They started investigations into solid modeling at the same time as their American colleagues and, from then on, continued to keep up with the international standard in CAD research. The fourth laboratory, under the guidance of Hans Grabowski and in accordance with the state of research and development in the second half of the seventies, the doctoral candidates of RPK at the Univerity of Karlsruhe, not founded until 1976, worked on improving the applicability of existing systems, the adaptation of American turnkey systems for use in German industrial companies[11], and the

---

[11]. For instance, Martin Eigner made a substantial contribution to the organization of databases which are also needed for the creation of 3-D volumetric models (Eigner 1980).

implementation of computers and the integration of programs of diverse research fields in all stages of the production process in a factory (Eigner, 1980).

From the aspect of engineering development, the WZL, IWF, LMK and RPK all made up-to-date contributions to CAD research, whereby each was outstanding in its own specific research approach. However, the analysis of the "non-technical" conditions under which the three institutes worked between 1965 and 1985 has shown an almost unrestricted dominance of the production-oriented research at the WZL and IWF. Both of these laboratories were not only able to quadruple their research personnel while that of the LMK and RPK remained constant, but their directors also occupied all principal posts in the self-governing bodies of the Deutsche Forschungsgesellschaft. The expert commissions of the DFG assigned funds for CAD research projects more frequently to the WZL and IWF than to LMK and RPK[12]. Moreover, the LMK was not able to carry out even a single project in the "computer-aided design" focal promotion program which corresponded to its own thematic approach, while the WZL and IWF received assistance for several projects in the same program. This clear under-representation of the LMK projects began in the second half of the seventies with the development of "solid models". At that time, the scientists at the IWF, oriented towards production technology, were defining "CAD" as a system which only served to prepare and plan production processes – i.e., following their own approach (Spur, Krause, 1976). Furthermore, both laboratories, first the IWF, and then the WZL, were extended by a Fraunhofer-Institute for promoting the application of research results to industrial practice. In the second half of the seventies, the federal government also decided to start a support program for the development of CAD/CAM systems serving the demands of production-oriented research. The dominance of production-oriented CAD research corresponded to the strong position of the machine tool industry as the top economic factor in the Federal Republic of Germany, but it did not provide a favorable result with regard to the introduction of CAD systems in industry. With the exception of the LMK's

12. The directors of the WZL, Aix-la-Chapelle carried out a total of 256 of the projects sponsored by the DFG between 1966 and 1985 (sum of the projects listed in the annual reports of the DFG). Of these, Walter Eversheim headed 55 projects. Within the same period, Günter Spur, IWF (Berlin) headed 44, Hans Seifert, LMK (Bochum), 23 and Hans Gabowski, RPK (Karlsruhe) 13 of the projects which were sponsored by the DFG.

design-oriented PROREN system, sold by a company that the institute director and his assistants had founded in order to by-pass the hidden boycott of the DFG commissions, no powerful system in West-Germany could be developed to be successfully commercialized by software firms. Up to the end of the eighties, not a single integrated CAD/CAM system had been developed up to the point of application maturity, nor was industry prepared to accept such systems.

Characteristics of CAD research in France: 1955 through 1985

Whereas the social conditions under which CAD research developed in the Federal Republic of Germany contributed to the dominance of research in one particular direction, the situation was quite the contrary in France. Since the late fifties, CAD research in France emerged from companies, and found its way into the research of the Ecoles Nationales and universities[13] from there. Even now, academic CAD research in France is still more closely linked with industry than in the USA or Germany. In 1958, i.e., two years after the APT project was started at MIT, Paul du Faget de Casteljau, a mathematician at Citroën, was given the task of developing a numerical definition for a casting mold, which could then be transformed into program instructions for a machine tool. Within two years, he succeeded in producing a magnetic tape for a milling machine using a purely mathematical definition of surfaces. Even though, from 1963 onwards, Casteljeau's method was used by draftsmen at Citroën, he was forced to keep his method in secrecy until 1985 (Poitou, 1988, 1989). Around 1960, without any knowledge of the work of Casteljau, Pierre Bezier, an engineer at Renault, began to develop the UNISURF system which was produced as a prototype in 1968. Reversing the procedure used by Coons[14], Bezier described surfaces, for example car bodies, by mathematically defining curves passing through polygons (Bezier, 1988). Right from the start, UNISURF was intending to integrate design and production data.

In the airplane and helicopter industry, for example, at the state-owned Aérospatiale and the partially private-owned Avions Marcel Dassault-Breget Aviation (AMD-BA), CAD systems were developed in the early seventies.

13. Jean-Pierre Poitou has dealt with the history of CAD systems in France in great detail (compare with Poitou, 1989).

14. Bezier met Coons for the first time in 1972; he had been reading Coon's reports since 1967.

Towards the end of the seventies, the integrated CAD/CAM system, CATI, (Conception Assistée Tridimensionelle Interactive) was created by F. Bernard at Dassault which was further developed and, at the beginning of the eighties, implemented in the production process by Michel Neuve Eglise before being extended to the CATIA system and then marketed by IBM (Neuve Eglise, 1981).

In France, academic research into CAD did not start until the late sixties. The first design-oriented CAD system originally emerged from studies on computer-assisted representation of the dynamics of fluids. In 1970, at the Laboratoire d'Informatique pour la Méchanique et les Sciences de l'Ingénieur (L.I.M.S.I.), a research laboratory of the Centre National de la Recherche Scientifique (C.N.R.S.) in Orsay near Paris, Jean-Marc Brun and Michel Théron developed the EUCLID system for visualising the effect of flow on objects, for example, on ships, which was represented by means of polygons. EUCLID is considered to be France's first "solid modeling" system. At first, Brun and Théron continued development on EUCLID at the C.N.R.S. up to its industrial maturity, supported by DBA, an automobile components manufacturer with American majority shareholders. After DBA pulled out, Brun and Théron founded their own software company, Datavision, in 1979, and in 1980 they sold 51% of their shares to the military division of the Matra-Group. In 1985, Matra-Datavision and Renault linked EUCLID to Bezier's UNISURF, which, in turn, had been combined with the French version of APT to become SURFAPT (Poitou, 1989-92 onwards). Quite contrary to the charcateristics of CAD research in Germany, in France, powerful CAD systems could be developed because of these continuing adaptions, integrations and commercializations of systems which had been developed within different contexts and for different applications.

In France, computer graphics-oriented CAD research emerged from computer science studies first conducted by D. Kuntz-Mann at the Institut de Recherche en Informatique et Automatique (IRIA) in Grenoble in conjunction with Michel Lucas's[15] attempts to visualize curve paths. Up to the present day, former members of the group around Lucas, for example, Denis Vandorpe, Laboratoire d'Informatique Graphique et d'Intelligence Artificielle, Claude Bernard University,

---

[15]. Michel Lucas now teaches at the Ecole Centrale de Nantes.

Lyon I, continue to carry out graphics-oriented research as well as research in other fields, such as standard interfaces for CAD/CAM programs, even though their main emphasis is design-oriented CAD research. A second research focus started at IRIA after a reorganization of research fields in the early seventies, when Jean-Marc Mermet began studies which served as a starting point for comprehensive production processes in the factory. Two of Mermet's pupils, Yvon Gardan, now head of the Laboratoire de Recherche Informatique (LRIM) at the University of Metz, and Bertrand T. David, Ecole Centrale de Lyon, Ecully, who both consider design-oriented CAD research as the indispensible starting point for the integration of CAD/CAM[16], have basically continued to follow this research approach up to the present day (Gardan, 1991).

Production-oriented research on the tool path control of NC programs, comparable to studies conducted at the WZL and IWF in Germany, started in France in military schools such as, for instance, under the guidance of Jean Pierre Crestin at the military college École Nationale Supérieure des Techniques Avancées (ENSTA), Paris (Crestin, Paillard, 1973).

The short overview of research approaches developed in France illustrates that all research directions developed in the USA had also emerged in France; however, as opposed to CAD research in the USA and Germany, it is difficult to clearly define the relative strength of the three main fields of CAD research. Yet members of both research lines, the design-oriented and the production-oriented research field, founded organizations for the purpose of supporting a general exchange of information about their own research results between science and industry. After the "Agence Nationale de Valorisation des Applications de la Recherche" (ANVAR), created by the C.N.R.S., had shown little success, the design-oriented science-based research field, promoted with great commitment by Yvon Gardan, founded the "Mission à la Conception Assistée et au Dessin par Ordinateur" (MICADO) in Grenoble in 1974. As a counterpart, Christian Sauvaire, representative of the academic CAD-NC military research sector, founded the "Agence pour le Développement de la Production Automatisée" (ADEPA) in the

16. As opposed to the Germans, CAD researchers in France defined French acronyms at an early stage: CAO, Construction Assisté par Ordinateur, FAO, Fabrication Assistée par Ordinateur, and CFAO, Construction et Fabrication Assistée par Ordinateur.

late seventies in order to provide the mechanical engineering industry with information on the results from CAM as well as CAD/CAM research[17]. In addition to that, the production-oriented sector provided workshops (Ateliers Inter-Établissements de Production, A.I.P.) distributed throughout France which are associated with computer science centers.

Summary

The international comparison on the historical development of CAD research in the USA, West Germany and France reveals characteristic research patterns in each of the three countries. Even though in all three countries the same research lines, computer graphics, the production-oriented and the design-oriented CAD can be observed, societal conditions in each country imposed an impact on the speed of development, the diversification of research approaches, the effort to reintegrate research lines or the implementation of the respective CAD systems in industry.

The characteristics of research on CAD systems at universities in the USA can be described as highly dependent on military funds even though from the mid-seventies onwards the industry and the NSF became interested in CAD research. Basic research at universities and applied research at software companies and in industries was separated from one another and, as a result of that, research and development phases could clearly be identified, at least up to the late seventies. Compared with the development in France and Germany, due to the specific market structure for CAD products in the USA, here, a commercially successful computer graphics research line was developed which is still attracting CAD researchers of the first generation.

The characteristics of CAD research in West Germany can be described as non-military funded research financed by the self-controlled German national science foundation and supported by the government. Paradoxically enough, the research line representing the interests of the strongest branch of industry, the machine tool

---

17. The association of production engineering founded in 1954, CIRP (Collège international pour l'étude scientifique des techniques de production méchanique) existed a long time before either of these organizations. The head of the institutes for production technology, Otto Kienzle (Hanover), Herwart Opitz (Aix-la-Chapelle), and H. Pahlitzsch (Brunswick), also participated in the founding ceremony.

industry, was funded the best, but did not result in the development of powerful CAD systems. Even though the development of computer graphics was neglected and the development of design-oriented research was hindered, scientists, industry and the government failed to notice that there was a need for appropriate design-oriented CAD systems in other branches of industry.

In contrast, in France, powerful CAD systems emerged from industry, above all, from the car industry. French CAD systems became economically most successful because systems developed within different research lines were combined with one another and constantly developed further. No unmountable walls were built up between design engineering and manufacturing, and scientist, of each direction developed a remarkable interested in cooperating closely with industry.

The cultural differences, observed in CAD research in the three countries, may also be characteristic for the development of other technologies in these countries. However, the analysis of CAD research at universities in the USA, France and Germany emphasizes the role of social groups involved in the development of new technologies and stresses the importance of democratic interactions among them in order to develop economically successful and ecologically and socially acceptable technologies.

Bibliography

Bargele, Norbert. PROREN2 – Eine Graphik Software zur dreidimensionalen rechnerinternen Darstellung von Bauteilgeometrien, Dissertation, Ruhr Universität, Bochum, 1978.

Bezier, Pierre. How a Simple System was Born, in Farin, Gerald: Curves and Surfaces for C.A.G.D., Academic Press, 1988.

Crestin, J.P. and Paillard, J.P. A Small Graphical System for Programming NC Machines, École Nationale Supérieure de Techniques Avancées, Rapport 027, 1973, paper presented at Prolamat 73, Budapest, 1973.

Eastman, Charles M. A General System for Computer-Aided Design, Final Report to the National Science Foundation, Grant No. MCS73-03492-A02, December 1976.

Eigner, Martin. Semantische Datenmodelle als Hilfsmittel der Informationshandhabung in CAD-Systemen und deren programmtechnische Realisierung auf Kleinrechnern, Dissertation, Universität Karlsruhe, 1980.

Eversheim, Walter. Konstruktionssystematik – Aufgaben und Möglichkeiten, Habilitationsschrift, RWTH Aachen, 1969.

Gardan, Yvon. La CFAO, Hermes, Paris, 1991.

Herold, Wolf Dieter. Der Einsatz der graphischen Datenverarbeitung in den Konstruktionsphasen des Entwerfens und Detaillierens, Dissertation, Ruhr Universität, Bochum, 1974.

Johnson, Timothy E. Sketchpad III, Three-Dimensional Graphical Communication with a Digital Computer, Dept. of Mechanical Engineering, MIT, May 17, 1963.

Krause, Frank-Lothar. Systeme der CAD-Technologie für Konstruktion und Arbeitsplanung, Dissertation, TU Berlin, 1976.

Kurth, Jürgen. Rechnerorientierte Werkstückbeschreibung. Ein Beitrag zur Rationalisierung produktbezogener Planungsprozesse, Dissertation, TU Berlin, 1971.

Mann, Robert W. Computer-Aided Design, in Piegl, Les (Ed.): Fundamental Developments in CAD/CAM Geometric Modelling, Butterworth-Heinemann, 1992.

Neuve Eglise, Michel. De l'idée à l'objet: Un système intégré de CFAO. Gads'arts 81, 1981, S. 25-34.

Olmsted, John M.H. Solid Analytical Geometry, Appleton Century Crafts Inc., New York, 1947.

Poitou, Jean-Pierre. CAD/CAM: Why, When, How? Some Examples in the French Industry, in Rader, Michael/Singert, Bernd/Riehm, Ulrich (Ed.): Social Science Research on CAD/CAM, Results of a First European Workshop, Physia Verlag, Heidelberg, Germany, 1988, S. 244-248.

Poitou, Jean-Pierre. Trente ans de CAO en France, Hermès, Paris, 1989.

Redmond, Kent C. and Smith, Thomas M. Project Whirlwind, The History of a Pioneer Computer, Digital Press History of Computing Series, Bedford, Massachusetts, 1980.

Reintjes, J. Francis. Numerical Control, Making a New Technology, Oxford University Press, New York, Oxford, 1991.

Rensselaer Polytechnic Institute, Rensselaer Design Research Center: Overview, March 1991, vervielfältigte Institutsschrift

Requicha, A.A.G. and Voelcker, H.B. Solid Modeling: A Historical Summary and Contemporary Assessment, in IEEE CG&A, March 1982, S. 9-24.

Ross, Douglas T. The Early Days of CAD, SofTech/MIT 89/10/03. A requested paper at the International Symposium "Advanced Geometric Modelling for Engineering Applications", No. 8-10, Production Technology Centre, Technische Universität, Berlin, 1989.

Seifert, Hans/Mitarbeiter. Rechnerunterstütztes Konstruieren mit PROREN, Bd. I und II, Schriftenreihe der Ruhr Universität, Bochum, 1986/87.

Simon, Rolf. Rechnergestütztes Konstruieren: Eine Möglichkeit zur Rationalisierung im Konstruktionsbereich, Dissertation, RWTH, Aachen, 1968.

Spur, Günter and Krause, Frank-Lothar. Erläuterungen zum Begriff "Computer Aided Design", in: ZWF Vol. 71 (1976), S. 190-192.

Sutherland, Ivan Edward. SKETCHPAD, a Man-Machine Graphical Communication System, Dissertation, Massachusetts Institute of Technology, January 1963.