Computer Aided Architectural Design Futures

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Computing has become a recognized art in the discipline of architecture, moving from the periphery towards the core of the design process. Research, education, and application are the critical areas that provide the development platforms for the future of design and computing. Seen in perspective, the term lineamenta *describes related activities in historical architectural research.* Research *also shaped the origins and early directions of CAAD. The first* applications *emerged after computers and software were powerful enough to implement high level ideas. Meaningful* education *of a wider audience of designers only became possible after the results of research proved promising.*

Figure 1. LINEAMENTA - CAAD. Instruments of a science of architecture. Poster for the Exhibition at ETH Zürich by Werner Oechslin and Gerhard Schmitt. Design Stefan Frei.

Lineamenta - an Historical Perspective

CAAD can build on a history and scientific theory of architecture which reveal an astonishing richness of ideas few of which have been fully explored. Many of the apparently new CAAD research paths have been tested before with different intentions. The findings of Werner Oechslin's research on the subject of architectural drawing serve as a good example (Oechslin 91). Since the era of humanism, when the modern theory of architecture was established based on Vitruvius, there have been repeated attempts to define and develop the architectural drawing as an instrument of scientific research. According to Alberti (1452) architectural drawing and design process are virtually identical: *lineamenta*. Literally translated, lineamenta stands for line, lines, or collections of lines. In Latin, a distinction is made between the abstract "lineamentum" and the literal "linea". Since Cicero, "lineamenta" has taken on a more precise meaning. Together with other attributes - form, interval, size - "lineamenta" becomes a part of geometry, a distinction that indicates the architectural significance of this label. Later two directions emerge. There is the desire to achieve coherence and compatibility between projections (plan, facade, section), stretching the meaning of Vitruv's text more than is appropriate, re-interpreting *scenographia* as *sciographia*. Parallel to this is the search for new and boundary crossing architectural possibilities per se, exemplified by Caramuel's *arquitectura obliqua*. The interrelationship between architectural drawing and the design process has always served to explore and re-define the creative possibilities of architecture.

The situation after the crisis of the French revolution is characterized by the attempt to simplify complex drawing processes and by the reduction of means to a minimum. Economy governs Durand's arguments in his "Précis des Leçons d'Architecture données à l'Ecole Polytechnique" of 1892. He summarizes all relevant previous literature in his book "Receuil et Parallèle des Edifices de tout genre, anciens et modernes". His contribution is the achievement of the ultimate degree of abstraction - "dernier degré de brièveté" - by reducing the drawing to its fundamental linear quality. The compressed drawing and composition methods of Durand demonstrate once again the relation between geometry and architecture. He also develops a new design method on a radically different basis, a different design method which he later calls "Marche à suivre" and from where he moves from the simplest drawing definitions - according to Albertian tradition - to higher degrees of detail. We have to keep this in mind when we use Durand's famous diagrams as a point of departure or justification for computer implementations.

Durand's most significant work in this context is "Ensembles d'Edifices, résultants des divisions du quarré, du parallélogramme, et de leurs combinaisons avec le cercle". Here he proves that even the most complex building typologies can be generated from geometric primitives and that therefore architectural richness can be achieved by deduction and generation. This is in accordance with the originally humanistic term of "more geometrico". It proves a new quality of relation between lineamenta and the disciplines of geometric drawing and systematic design process and has therefore been a most influential book for decades.

Even more interesting for future CAAD systems are the attempts at systematic formalization of the aesthetic. Alberti's term "concinnitas", often too directly translated as aesthetic in the modern sense, still maintains in its definition the relationship with geometry and mathematics. Following the discussions of style and taste in the 18th century, the triumph of the sensual view, and even after the definition of the modern term aesthetics, there were attempts to define the aesthetic dimension of an artifact by quantification or other scientific means. In the tradition of a geometry-based architectural theory, the richest form could become the most desirable. Hogarth in "The Analysis of Beauty" (1753) uses the double serpentine line as a symbol of variety but treats the aesthetic question as a concept that is impossible to calculate and define. John Ruskin defines a "line of beauty" for the integration of a "British Villa" into its surroundings in his article "The Poetry of Architecture", published in 1839 in London's Architectural Magazine. He maintains that nature and architecture should be composed and orchestrated in their interaction as firm geometric lines.

Towards the end of the 19th century, notions on the causal relationships between form and aesthetic value and form and significance appeared in increasing numbers in articles on ornaments. Even the classical work of D. Birkhoff, "Aesthetic Measure" (1933) points in this direction. The concept of "numerical aesthetics", which sought to capture the aesthetic value of Velasquez' famous "Hilanderas" by quantifying the elements and configurations appearing on the surface of the canvas (G. Cavallius 1972), came to yet more extreme conclusions. Such attempts were as futile as those made to capture the aesthetic value of modern or historic buildings through arbitrary grids for geometric primitives alone. They do, however, point to a fundamental challenge to the digital world: Now that the new instruments have proven their potential usefulness, they are expected to become intelligent and knowledgeable, after which they may be expected to show taste and style and eventually truly support architectural design. This brings us to the present and the efforts to improve the worldwide state-of-the-art in CAAD. For the first time in history, progress is being monitored in real time.

CAAD futures '91

The triad of CAAD research, education, and application is very dynamic in character and has undergone radical changes in its short history. Universities and sizable design firms were the original institutions of *research.* Today, large CAD software firms and some hardware producers have their own CAD research centers or directly subcontract universities. Not surprisingly, this has influenced the direction of inquiry, placing greater emphasis on applications rather than fundamental research. Although *education* has traditionally been the domain of universities, the high demand for CAD literate personnel in architecture and design offices has lead to the establishment of independent training centers in design firms and CAD software houses. Universities have also become more dependent on commercial software to keep up with the rapid advances in capabilities and the new principles of thinking. *Applications* were and are developed for practice. This field has undergone the most dramatic change in the past decade: from a few thousand installations and users in the early 1980's the base has grown to more than one million CAD users worldwide. In the same period, architectural CAD installations have increased from a few hundred to almost 200,000 worldwide. The sheer number of users indicates the growing importance of applications in shaping the future of CAAD. Developing CAD programs has become an industry as well; whereas individuals developed and sometimes even marketed earlier programs, this has now become the exception. Teams consisting of several dozen members (IEZ in Bensheim with Speedikon) and up to several hundred members (Dassault in Paris with CATIA or AutoDesk in Sausalito with AutoCAD) are now involved in the development, updating, and marketing of CAD programs.

Figure 2. Lineamenta - CAAD. Generation of form with parameterized elements, using ArchiCAD. Models Doenz, Fries, Osman, Graser and Steiner in a CAAD course at ETH Zürich by Gerhard Schmitt. Rendering Eric van der Mark with Wavefront Advanced Visualizer.

CAAD Research Futures

It appears that a research environment is ideal for defining and shaping the future of CAAD: Relatively free of economic, time and special interest group pressure, researchers can search for the truth. They would work according to Ulrich Flemming in two areas: (i) gaining insights into the design process and the human cognitive apparatus, and (ii) finding methods to improve the design process or its results (Schmitt 90). Supported by a large and steady stream of funding, they would finally solve the problem of knowledge representation, break the complexity barrier, define the relation between geometric and symbolic representations and find the ideal graphics and information exchange standards. All knowledge gained could be recorded and made available for future generations as fundamental truth.

Reality is different. Research in CAAD is both benefitting and suffering from the fragmentation of the design and building industry. In most industrial and post-industrial countries, the AEC industry contributes a major share of the GNP, yet there exists no category for architectural design research in national research programs. Thus, architectural researchers must creatively collect their support from various sources under different funding schemes. Within the design research community, discussions about fundamental versus applied research are common. In addition, the design of new computer programs is also referred to as research which poses a similar problem to that of labeling architectural design as research. Understanding and formalizing the design process are at the core of many projects, because it seems a prerequisite for the development of intelligent design support systems. The developers of such systems must acknowledge the fact that there is no single design process, and that for any given design process properties of the results of traditional scientific research such as repeatability and quantifiability may not be found. Built architecture provides architectural historians with some of the opportunities which researchers in the fields of physics or chemistry take for granted. In such cases, one can expect to discover elemental principles and fundamental laws. Yet exploring the dynamic and under-constrained process of design is research on a moving target which calls for new methods and instruments.

Not surprisingly, research and development in CAAD had split into several branches by the beginning of the 1990's. In this book, exponents of some of these fundamental streams report on their progress and findings. The discussion about the advantages of *design automation* versus *design support* is ongoing. The consensus seems to be that there will not be, and should not be an autonomous architecture machine, but rather that research should focus on the invention of intelligent design support systems. Investigation of *generative systems* and *grammars* in particular has already resulted in a number of elegant implementations (Mitchell 90). So far, grammars have mainly proven useful for the partial analysis and reconstruction of past architecture rather than in the complete synthesis of new architecture. *Knowledge-based systems* (KBS), a much used AI term in recent years and long believed to offer a solution to some of the problems of architectural design, are being fundamentally challenged from several sides. There are claims that knowledge not connected to the human being is useless or worse, and that without common sense knowledge KBSs cannot perform even the simplest tasks. *Case-based reasoning* may be a superior method for representing complete cases and their inherent knowledge without searching for causal relationships between function and form. Case adaptation and case combination appear to be promising techniques for handling the complexity of architectural design. *User interfaces*, besides representing the largest part of the source code in any CAD program, are finally recognized as a key research area.

As exciting as findings in these areas are, a few words of caution are necessary: The field has grown so rapidly that no single human being can be an expert in all areas, which has effectively placed the goals that Sutherland and Negroponte placed on the agenda more than two decades ago out of reach. The historic perspective seems to be dangerously missing in most of the projects, the absence of which poses the question of relevance. Knowledge is being gained vertically much more rapidly than horizontally, thus creating the impression of islands of knowledge that are unable to communicate with each other. It has become necessary to specialize in order to survive the competition for resources. This reaffirms the importance of fundamental discoveries that are of value for the entire field. Most of all, it appears critical to keep in mind the overall goal and vision of architectural research: To improve the quality of the built environment we live in.

CAAD Education Futures

In the 1990's software tools and hardware have reached a quality that requires a major re-evaluation of previous assumptions. A new generation of architects, educators and students has evolved which approaches CAAD with less bias and prejudice than was the case just ten years ago. Surprising and unexpected directions in architectural form and presentations are the result. A new agenda for CAAD education is essential.

The needs of practice and the availability of new tools, taught at increasingly competent training centers, define the agenda for CAD *training*. The future agenda for CAAD *education* is more difficult to define as human and financial factors within academic environments will influence its development.

The human factor. The easy days of teaching CAAD are over. Competition from other courses is strong and the field has grown to such an extent that educators must make decisions about which topics are most important. The quality and nature of commercial products reduces the chances for individual educators to have an impact on future CAD products. CAAD educators face the dilemma of becoming obsolete - once new software becomes powerful and user-friendly enough - or of invading the domain of design teachers. The latter is inevitable if the advantages of computing in design are to be taught professionally and convincingly. The number of software users is increasing at a much greater rate than the number of software developers, which might explain the lack of fundamentally new ideas over the past 15 years. It also indicates the need to educate more concept and program developers.

The financial factor. Taken seriously, CAAD education will turn architecture into one of the most capital intensive teaching subjects. Extremely high demands with regard to graphics speed and quality, unusual output media and sizes, differentiate architecture from other disciplines. Hardware donations may subside, in which case all hardware and software would have to be purchased and maintained within restrictive academic budgets. This would give financially strong universities a significant advantage.

Education in CAAD has moved from the fringe to the mainstream. There are few architectural schools in North America that do not include one or more CAAD courses as essential components of their curriculum. Europe is following quickly. The relatively late introduction of CAAD in Europe has had an interesting and possibly revolutionary side effect. Educators are of a younger generation. They view the instruments that they teach with differently than the pioneers of CAAD who are still familiar with the awkward earlier tools. The even younger students begin with highly superior instruments compared to their colleagues of a decade ago and have access to a fairly large body of work on the reconstruction of past architecture. What they still lack are examples of good architecture that has been produced with the new tools. So they set out and explore - a most exciting example is the recent “Soft Targets - Visions in Space” exhibition completed by students from the Technical University of Munich in October 1991. By using all of the modeling, projection and visualization technologies that have been developed in recent years, they were able to create an excitement that changed people's view of CAAD (Schallhammer 91). The "Lineamenta - CAAD" exhibition at the ETH Zürich presented in conjunction with the CAAD futures '91 conference in July 1991, also used student work to show new possibilities for generating, modeling, and visualizing virtual architecture.

Given the availability of data bases, knowledge bases and the new possibilities in visualization and presentation we must not forget to educate students to ask fundamental question about the purpose of design and technology. As the space for exploration opens up with the introduction of new instruments, an historic perspective and a convincing theory and discipline for applying computers in design become even more important.

CAAD Application Futures

The area of applications is expanding most rapidly. With few exceptions, applications concentrate on what could be termed design support at various levels. Yet there is still no conclusively integrated design package. Insular solutions to selected problems characterize the market. There are few programs which integrate more than two aspects of design such as graphics and structures or energy and cost evaluation (Haldemann 91). Some reasons for this are, the limitations of design data bases and representations, and the lack of semantic filters in modeling and presentation. With the number of users still growing rapidly and in the absence of a broad CAAD educational strategy which focuses on the new possibilities for designing with computers, traditional paper-based metaphors and paradigms are still understood best, they are the easiest to learn and therefore dominate the application market. Several authors in this book will point to the fact that a paradigm change in design will have a serious impact on the practice of architecture and the AEC industry in general. Here again, a convincing application, successfully marketed to architects, might change the perception of what can and cannot be done. It appears that new developments in application programs do not necessarily take hold due to their merits, but rather due to successful implementation. As an example, several viable standards for exchanging design information such as IGES and STEP have been proposed. Yet the market has made DXF the de-facto industry standard, although it is in some aspects inferior to the two others. A second example is the sudden widespread proliferation of graphics libraries such as GL, although theoretically the system independent GKS or PHIGS graphics packages offer greater advantages.

Natural user interfaces are of crucial importance for CAD application programs, particularly for novice users. New interface paradigms still do evolve and the range of physical input devices is growing even faster: keyboards, screens, mouse, pen, dials, space ball, data glove, just to name a few. It is interesting to note that pen-based computers are now marketed as the latest in technical development while they rely on a traditional input mechanism perfected over centuries.

The majority of new programs fall into the category of CAD productivity tools. As in research, progress has occurred vertically within design activity areas but not horizontally. A typical example is the DOE-2 energy simulation program: After more than 15 years of development, there is still no graphical or at least user-friendly interface, although it has been proven that DOE-2 can be used as an effective design tool. Specialists in energy simu lation do not need graphical input, and designers do not use the program because of its awkward non-graphical input mechanism and overwhelming set of options.

Similarities between natural language and design language do exist and have been the subject of extensive research. Yet differences become clear very rapidly when one searches for the design counterpart of word processors, outliners, spelling and grammar checkers. In the restricted and - compared with architecture - highly constrained space of natural language vocabulary, there are enough conventions and sufficient known semantic content to allow the processing of data from different points of view or through different filters. Even so, countless unexpected and undesirable confusions can occur, thus effectively preventing automation. In parallel, design productivity could definitely improve if a shape processor, a design element checker, a design grammar checker, and design outliners would exist in an integrated program. Then even designers might use computers.

Conclusions

It has become clear that CAAD will have not one but many futures, shaped by academia, practice, and business. Scientific methods in architectural research have helped to create a foundation of knowledge on which new CAAD research can build. Consequently, CAD programs first concentrated on the most formalized product, the architectural drawing. The art of abstraction, essential for the communication of architectural ideas, will not lose its significance even in the age of virtual reality. Lineamenta can serve as the link from the past to demonstrate possible future developments.

Future CAAD systems should be useful, intelligent and eventually support properties in the class of taste without limiting creativity. For this, we must understand the almost mythical link between architect, drawing, and completed building. We also must realize what we may surrender by replacing the traditional process of design with new modeling and interaction techniques. Aesthetics is one of the challenges for the next generation of CAAD systems because there is no reason to exclude any of the properties of architecture from the processes of understanding, formalizing, and explicating. Whether or not we shall succeed is not the question, but rather how we will proceed to investigate such seemingly unquantifiable properties of architecture. Nothing would be more devastating for the young science of computer aided design and for architecture than the creation of new taboos.

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