Chapter 15

CAAD: Shorter-term gains; longer-term costs?

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15.1 Introduction

Assessment of CAAD systems in use is complex: it needs careful qualifications and is often contradictory. It is suggested that little progress has been made in making sense of the impacts of computing on design and design organizations. Impacts are more diverse and complicated than has been assumed. Assessments tend to be either overtly optimistic or pessimistic, yet the need is to be realistic. Moreover, impacts have been the subject of speculation and marketing rather than systematic study. Carefully documented case studies of projects or longitudinal studies of organizational impacts remain the exception. This chapter draws upon recorded user experience reported elsewhere (Walters, 1983)1 and presents an assessment of the performance in use of current production systems. It presents an end-user view and also identifies a number of outstanding design research topics.

It is suggested that different systems in different organizations in different settings will give rise to new impacts. A wide variety of outcomes is possible. It seems unlikely that any simple set of relationships can account for all the data that inquiry reveals. The task becomes one of identifying variables that lead to differential outcomes, as the same cause may lead to different effects (Attewell and Rule, 1984). This becomes a long-term task. Each optimistic impact may be countered by some other more pessimistic impact. Moreover, the changes brought about on design by computing are significant because both beneficial and non-beneficial impacts are present together. Impacts are held in a dynamic balance that is subject to constant evolution. This viewpoint accounts for otherwise conflicting conclusions.

It is unlikely that the full range of impacts is yet known, and a wide range of impacts and outcomes already need to be taken into account. It seems that CAD alone cannot either guarantee improved design or that it inevitably leads to some diminished role for the designer. CAD can lead to either possible outcome, depending upon the particular combination of impacts present. Careful matching of systems to design organization and work environment is therefore needed. The design management role becomes crucial.

Attention is drawn to both the short-term gains and the longer-term costs associated with the use of current systems. Gains are well publicized. They included an improved design representation and the 'PR's -improved productivity ratios and public relations. Gains have to be secured continuously, so tend to be short term but, more importantly, experience is gained that contributes to the long-term ability to compete. The costs-in-use of systems are less well known. They tend to be longer term, are significant and include:

(1) The cost of providing the right conditions for system use; and
(2) The costs of system evolution as hardware, software technologies, system design concepts and user design practices change.

The following review of user experience highlights costs associated with maintaining the right conditions and from evolving systems. It also assesses limiting factors placed upon cost-effective use. The pattern of actual costs and benefits obtainable with current production systems is developed. User learning is shown to be needed not only in terms of system operation but also in terms of system, database and design management.

15.2 Findings from user experience

Distinctions need to be maintained between design and production systems and between modelling and drafting systems. Based upon the material presented in the case studies a personal view of the performance in use of current production systems is developed. In the examination of the casestudy material it is frequently difficult to differentiate between system performance and the adequacy of user practice. Assessment is complex, needs careful qualification and is often apparently contradictory.

15.2.1 Results from case studies and other user experience

The case studies highlight:

(1) The lack of shared models of building and design processes within the design team. User practice is both idiosyncratic and unstable.
(2) The close relation between design and modelling systems and their users' design practices. Examples include:
   (a) The general inability to exploit high-level input (automatic detailing); and
   (b) The need to invest in data. Also, there is often a need to rearrange user design practice around the requirements of CAD input.
(3) The little direct impact of CAAD on the product but a much-changed design process.
(4) The benefit of the accumulation of user experience and data.

The case studies and other user experience confirms:

(1) The high productivity ratio attainable on specific drawing tasks, on large projects with a repetitive element, where there is also an investment in user technique, training and data.
(2) The curious relationship between drawing-system use and user design practice. Drawing production is often divorced from design development and hived off as a specialist task.
(3) The necessity of limiting CAD objectives and establishing the right

conditions. It is of interest to note that the original list of right conditions (orthogonal geometry and building system context) is much changed. These conditions are no longer seen as necessary and the original list was far from complete.

15.2.2 Detailed assessment

Use of current production systems suggests the following.

Implementation

(1) Implementation generates more difficulties than is anticipated because of the user technique necessary to support data consistency and because of the CAD and design management issues raised.
(2) Development is often over-ambitious and premature in relation to: (a) Knowledge of design and of the nature of user practices; (b) Performance of available implementation tools; (c) Cost of available suitable hardware; (d) Level of development of design data and standards; and (e) Knowledge of the effects upon and the relationship with design practices.

Performance in use

(1) CAD rationale (resource distribution and shared image) does not take adequate account of the full life-cycle costs and of design team attitudes.
(2) Systems are restrictive because of the concepts, implementation tools and user interface design employed but they remain powerful and often show improvements over traditional techniques.
(3) Choice of implementation tools is crucial. The trade-off between power and ease of use is crucial in the design of the user interface.
(4) System support for the content (as opposed to the fabric) is better due to the lack of relational complexity.
(5) System facilities provided for high-level input and data consistency are unusual and much needed. Current facilities are inadequate in practice.
(6) Detailed design systems associated with the fabric are generally not robust enough to withstand inevitable changes in user practice.
(7) Different systems each have their own particular performance profile against the following key issues for system design and use; i.e.
    (a) The capacity and robustness of the system;
    (b) The completeness of the geometric model;
    (c) Facilities for non-geometric information;
    (d) Facilities for maintaining data consistency;
    (e) The right conditions for use;
    (f) The design of the user interface and the handling of input; and
    (g) The imposition of a procedural model of design.

Systems design may be seen as an inevitable compromise.

Effects in practice

(1) CAD methods are not robust in the face of uncertainty over design development. They do not support multiple options or tentative decisions. Database integrity management in the face of design development is an important aspect of user technique. Maintaining the design description costs more than its initial creation.

(2) The lack of any shared model of design procedure prevents more widespread acceptance and also prevents realization of full benefits of application across professional boundaries.

(3) While design systems can be found wanting, so also is the design team's current ability to use them. Changes in design practices are needed to accommodate system use.

(4) High development costs must be set against more than one major project and benefits from the product. These major potential benefits are not easily quantified. Costs may have to be shared between competing design organizations.

(5) Systems are restrictive but they still have to be fully exploited.

(6) CAAD can be seen to be a comparatively small part of the overall design working but it requires much of the design process to be organized around CAD use to achieve results. It tends therefore to have an exaggerated effect upon design practice.

(7) Explicit validation of subsystems is seldom possible. In this situation individual professional attitudes are important.

(8) Distinct patterns of benefit exist; savings from the design process are less than potential capital-cost savings; both are less than revenuecost savings. Within the process there are both direct and indirect savings. Direct savings show a high PR on specific tasks but also tend to the marginal overall and are realizable only after further investment in user technique. Measurement of productivity is difficult.

(9) System use has important training and staffing considerations. User learning must be seen as not only operator skills but also system management, database management and design management, each with its own time scale. Learning is completed over a range of projects.

(10) Project development cycles and the currency of user practices can be seen to be in conflict with both hardware and software life cycles. Software maintenance costs, where there is a close relationship to user design practices, are prohibitive.

(11) With CAD there is an inertia which requires the maintenance of procedures and standards in order to exploit previous investment. The cost of system evolution may be seen to be crucial in this context. Standardization should not be seen as either always inevitable or inappropriate, but as a matter of design policy.

Overall assessment

(1) The difficulties raised should not limit wider acceptance of systems but should help to develop a coherent end-user view of design systems generally. This view is urgently needed.

(2) System use, whether integrated modelling or drawing system, raises a

number of related database management, design management and policy issues which are of strategic importance to design practice.

(3) A difficulty exists in maintaining a balanced view of design as impacts have to be held in balance. Gains, in relation to tradition practice, are significant but costs can also be high.

15.2.3 State of the art in practice

The state of the art in practice is as follows:

(1) Satisfactory (sometimes spectacular) results may be obtained from current systems under the *right conditions,* keeping CAD objectives limited and operating with *limiting factors* exploiting the *pattern of actual benefits*. The right conditions are shown in *Table* 15.1. They include:
   (a) Effective management control of project and CAD costing;
   (b) Effective development of office and project organization and procedure to meet the requirements of efficient input operations; and
   (c) Adequate accumulation of experience, data, training and support.

   Limiting factors must be allowed for as follows:
   (a) Level of agreement on design procedures and data standards;
   (b) Ability to maintain data integrity;
   (c) Level of available user technique, training and support;
   (d) Prevailing working practices in terms of plans of work, conditions of engagement and design team attidudes.

   The pattern of actual costs and benefits has the following features:
   (a) System design development and use tends to have a classic pattern of investment opportunity in terms of risk and reward;
   (b) Design systems may seek reward from capital and revenue savings; production systems must seek returns within the design process;
   (c) Direct returns within the process tend to be marginal overall and dependent upon user technique. High returns are confined to specific tasks. Gains must be continuously secured; and
   (d) Many potential benefits lie across traditional professional boundaries.

(2) Current systems provide an improved design representation in terms of improved accuracy and ease of manipulation and may be predictive rather than merely descriptive; representation is only at a low level of abstraction.

(3) Current systems are better suited to engineering product design than to building design problems due to:
   (a) The lack of stability of user building design practices;
   (b) The lack of any consensus on appropriate models and procedures for design development;
   (c) The large number of parts and their complex interrelations in any building; and
   (d) Fragmentation of the building design professions.

(4) In practice, drafting is more widely accepted and more cost effective than modelling for production systems.

Table 15.1 The right conditions for CAD

General	Project selection - size and repetitive element Level of user commitment and technique Level of user experience and data development Limited objectives and right conditions Record rather than develop solution
Management control	CAD integral to design organization Office and project management control essential prerequisites
Job costing	Review project costing procedures to monitor reinvestment Determine level of detail required to monitor effects of CAD introduction
CAD costing	Cost-benefit framework Determine workstation rates, peak/off-peak, relation to office overheads, target utilization Integrate with jobs and office costing
Plan of work	Identify new procedures, e.g. option evaluation, room layout documentation, arch./eng. drawing co-ordination. Clarify level of service, roles, resources, responsibilities, liabilities, programme and agree conditions and fees Relationship to other projects and library data development; long-term objectives
Project procedures	Project information structure: primary and secondary: coordinating framework for manual and CAD information; CI/SFB, overlays Drawn information structure: relationship to library data, data standards and structure Personal information or agreed conventions; updates Drawing practice; CCPI conventions Relational information; implied or explicit Prerequisites for stage F (Styles 82) Handling of two records Agreement on practices, within office, within architect's design team, within design team
Organization/working relationships	Office structure: number of staff, same or different staff, flatten pyramid Core teams for CAD and library New roles: designer of design systems, db manager/ CAD coordinator, systems manager Design team working: integrated working of design team, review of existing procedures re. coordination, agreement on roles, resource allocation and costs and responsibilities for abortive work, local or institutional agreement Client relationship: improved access to design process, option evaluation, PR
Programme/Resources	Workstation utilization and allocation: shift use, available staff, Productivity Ratio on workload, coordination with project programme and build-up of library data Form of interaction: designer, system operator or both Resource management, handling peaks
Accumulation of user experience	User technique: see case studies MKDGH 8.3 User technique Wexham 3.4.1 Preparation of Input Wexham 3.5.1 Updates and Procedure Manage period of transition Make simple, low-boffin factor Learning completed, data developed over a range of projects
Training	Timing: in relation to production - offpeak in relation to installation - secure benefits of mature learning curve Topics: system operation, system management database management, design management

Table 15.1 *(continued)*

	Investment in people, career structures to keep key staff
	Staff assignments to maintain fluency
Support	*Hardware and software maintenance agreements*
	Documentation
	Trouble shooting, daily management, security
	Professional support
Other	*Building system or strictly orthogonal geometry no longer*
necessary	
	Design and database management essential prerequisites. CAD
has	
	to be made to work

15.3 End-user view

Experience may be used to generate an end-user view of current systems. The development of this view of systems is dependent upon:

(1) An assessment of current systems in practice: what systems do well, handle geometry; what systems do badly, handle design development; what system do not do at all, handle relational complexity in building design and support the development of user design practices.
(2) Insight into system design issues and the inevitable trade-offs to be made in terms of the key issues for system design and use.
(3) An assessment of the rate of the emergence of new system design concepts and software techniques. These are considered in turn.

15.3.1 System performance: an overview

Further detailed case studies covering a wider range of projects, practices and systems are required to refine an end-user view of design systems. However, it is suggested that current systems appear useful but flawed. They:

(1) Are inevitably compromised in their system design;
(2) Provide insufficient user support for data-integrity maintenance;
(3) Cost too much to develop, implement and, more particularly, evolve;
(4) Fail to provide a satisfactory relationship between system use and user design practice.

This view raises important system design issues that can be approached equally through modelling or through drawing systems. They both currently fail, though in very different ways, to satisfy the need for an appropriate relationship between system use and user design practice.

15.3.2 System design and user practice

Modelling may be seen to be conceptually more advanced in several important respects:

(1) Reduction of redundancy.
(2) Enforcement of data integrity.

(3) Completeness of representation and support for extended applications.

However, in practice it is seriously handicapped by practical difficulties, i.e.

(1) The user interface created;
(2) The reliance upon the prior declaration of system concepts; (3) The acceptance of a procedural model of design;
(4) The difficulties arising from the extent to which it is possible to sustain the right conditions, overcome limiting factors and secure potential benefits. Notably, the costs of training and data development are high.

The close relationship between any modelling and user design practice is evident, as the system is the primary record of the design solution under development. It is also an expression of user design policy in terms of the system concepts, data and procedures employed. This relationship reduces the acceptability of a modelling system to any other user and also to the original user as his own practice develops.

The ability of conventional software technology to economically support either customization, or the evolution of systems in response to users changing views of their needs is poor. The evidence present in the case studies confirms this argument first developed at EdCAAD (Attewell and Rule, 1984).

Drafting is a simple concept. Divorcing the drawing from the underlying physical reality obviates the need for any consensus on user design practice as all drawn relations remain implied. It is for this reason that drafting systems find wider acceptance and attract commercial interest. The inherent weaknesses in the approach, i.e.

(1) High redundancy;
(2) Poor support for data consistency; and
(3) Difficult extension in support of other applications

are not explored so long as CAD objectives are kept limited. Extending the drawing system as a design database is possible only in certain specific applications contexts. Such extension runs the risk of reducing the overall level of benefit. User responsibilities for data consistency (in terms of object/symbol structuring, naming and attribute data collection) become too onerous, reducing the efficiency of input. Drafting is cost/effective as long as it is kept simple.

Satisfactory results may be obtained with either approach but more readily with drafting. Both production systems fail, however, to introduce an appropriate relationship between system use and user design practice. A distinction can be made in the way each approach fails. Modelling implies a close relation, and this demands costly customization to suit individual practice and thereby win acceptance. This relationship is then vulnerable to the subsequent evolution of the user's own practices.

Drafting systems deny any relation between system use and design practice at a conceptual level. In use, however, in order to control input efficiently and in order to support efficient processing (particularly drawing editing by a number of users) it is necessary to introduce modelling concepts in support of object/symbol definition. This reorganization of drawing practice introduces an unfamiliar workload and raises the now familiar set of design and database management issues. Further, the user, because of the high cost of input, is tempted to extend the drawing database into other applications.

A direct consequence of this relationship is the increased specialization of drawing production. Design and drawing are no longer integral. The effect is to introduce 'graphics processing' and to reduce CAAD to an application of no greater sophistication than word processing. It is ironic that triviality at a conceptual level should lead to increased specialization of the drawing production function. Drawing production and thinking about what is being drawn (i.e. designing) are thus artificially separated.

A criticism of the state of the art of production systems, implemented in conventional software technology, is that effective production system use is generally confined to 'graphics processing'. The extent of this restriction is made clear with insight into the trade-offs made in system design.

15.3.3 System design trade-offs

The pattern of trade-offs between the different production systems is as follows:

(1) Modelling:

Desirable features are secured at higher cost:

(a) Capacity, robustness; and
(b) Greater completeness - geometry, database facilities, integration of functional and physical models and range of applications

offering powerful facilities through procedural expansion and tightly structured data giving a design representation that has

(a) Low redundancy; and
(b) Greater data consistency

in return for *less desirable features:*

(a) Prior declaration of procedural model and system concepts;
(b) Form of user interface and less ease of use; and
(c) Less general acceptance and greater dependence on the right conditions.

(2) Drafting:

Desirable features are secured at lower cost:

(a) Capacity and robustness;
(b) No imposition of any procedural model giving wider acceptance; and
(c) Easier implementation of user interface combining to lessen dependence upon the right conditions;

in return for *less desirable features:*

(a) Reduction of completeness - two-dimensional geometry only, a lack of database facilities, integration of models and applications supported;

giving less powerful facilities storing unstructured data leading to design representation of

(a) High redundancy; and (b) Poor data consistency.

Developed using conventional computer technology with the inherent cost, power achieved and acceptance found, neither of these approaches achieves an appropriate balance between the full range of system design issues at reasonable cost. The criticism of the level of the performance in use of current software technology is that it is well worth making the tradeoff implied by drafting-system use.

This, combined with the inappropriate relationship found between system use and user design practices, leads to the suggestion that current production systems are flawed. This is not to deny the benefits that are already available but to attempt to place state-of-the-art systems along the evolutionary path to maturity.

15.3.4 Outstanding research

Bringing CAAD systems into a more appropriate relation to user design practices appears a long-term objective. The need is for new system design concepts as well as new implementation strategies and new software techniques. Matching machine functions to user practices and design system concept evolution can, however, only develop through trial and error. Also required is new research in support of:

(1) New software techniques which can economically support the user-controlled evolution of system development and design practices;
(2) Computer-aided database integrity maintenance facilities; and
(3) Building description (as opposed to geometrical modelling) and the relational complexity in the functional and physical models of building with a view to their integration with the spatial model.

The need is for users to be able to undertake their own system design using their own concepts, developed and implemented within the design fee for one job and subsequently abandoned. This is the goal to be set for future systems. In this way systems will evolve and support user practices and will not be undermined by idiosyncratic practices and the lack of shared models. The outstanding research in support of this goal and the necessary software development appears substantial.

Design practices must change to secure and accommodate benefits, but system use ought not to change the fundamental nature of design. Future systems must anticipate future design practices. This relation needs to be widely debated. Design research now must support this debate in a way that it has failed to do in the past. Design effectiveness, like management effectiveness (Peters and Waterman, 1982) depends upon more than appropriate systems. Greater understanding of the nature of design practice and designers' methods is now urgent if systems and practice are to evolve together. Information use in design receives little attention. The relation between calculation and judgement in design needs further definition. The view we take of the nature of design then becomes critical (Holt et al., 1985). Design is more than problem solving.

15.3.5 Current research - hope and performance

Exploitation of emerging computing research offers hope of progress in this direction. Future design systems have been anticipated (Priess, 1983; Bijl, 1982) and new software technology, notably knowledge engineering and logic programming together with relational database systems, offer the prospect of significantly improved user interfaces and a 'non-prescriptive' computing environment better suited to supporting changing user needs at lower cost.

A number of other topics, including new abstractions, abstraction hierarchies, aggregations, semantic integrity and dynamic schema extension, are important (Eastman, 1980). Geometric modelling can be seen to be advanced. The development of a theoretical base for building description is, in marked contrast, weak.

If CAAD is to become the principal medium of representation then there will also be a demand to represent knowledge of design and drawing practices, design goals and integrity constraints, design contexts and design heuristics. These topics are characterized by their importance to the development of CAAD and their slow emergence from research. This is the reality. Topics that are crucial to design - self-directed open-ended learning, analogical reasoning, integration of knowledge from different domains, distributed memory and processing - have only just secured places on Al's long-term agenda. Continued advances in hardware, operating systems and graphics techniques and standards can, however, be anticipated with relative certainty. Development of new design systems concepts seems more problematic. Computing and design technologies evolve on different time scales.

15.4 Transition

Given the developments that remain outstanding and the wide range of disparate topics that support any CAAD system, each with its own development time scale, a period of transition may be expected. Substantial benefits may be secured with current systems under the right conditions. Users must learn in this period of transition to:

(1) Keep their CAD objectives limited to maintain cost effectiveness and to maintain validity independent of context; and
(2) Support those organizations that show a concern for their unique requirements in any CAAD system.

Implementation in this period does not present easy choices. The need for a 'growth path' has been shown by EdCAAD (BijI, 1982). However, current systems (with adequate capacity) demand a high and quick return on investment. This may be compromised by the need to anticipate future systems. Long-term planning is necessary but actual commitments have to be kept short term. The transition and the nature of current systems has to be treated as the determining factors in the implementation strategy. Conflicting pressures on users may be severe. A coherent end-user view of systems may be seen as the best guide during this near-constant transition.

Two general lessons about systems use are clear:

(1) Our tools do both enable and constrain (Vickers, 1984); and
(2) Our tools do modify our perception (Weizenbaum, 1984).

Use does have longer-term impacts yet outcomes are not predetermined. Critical reflection upon use retains choice. Our systems are increasingly necessary but they are not sufficient. They inform, but they do not replace human intervention.

As future acceptance can be expected to increase, so too can sophistication and specialization. Applications using conventional software technology can be expected to grow, given the existing commitment. Drafting will dominate production system use but a wider variety of hybrid systems will emerge. Detailed subsystem evaluation (single-function system) will be the main design system application. Facilities/estate management will a key applications context. Fundamental issues will remain outstanding. Both the threats and promises are real but the balance of impacts may be manipulated to advantage through design management. Making sense of the range on impacts of computing on design organization and upon design effectiveness is the key to CAD management effectiveness.

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