A Time Dimension for Computer-Aided Architectural Design Systems

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This paper presents the importance of a time dimension for CAAD systems and describes the idea and research intentions to implement this dimension as a new aspect of design information. A time dimension is proposed as a tool for the organization of design information and for the reproduction of design processes. The aim of the research is to propose a facility to record all design states generated during an architectural design process, in a temporally coordinated manner in one information system. Such an information system should make it possible to have the computer register and reproduce the design process in a procedural manner and compare different design states. This will lead to a better analysis and evaluation of design states and to a possible analysis and evaluation of design processes.

Keywords: computer-aided architectural design, time, time dimension, temporal aspects.

1 Introduction: The Case History

During a design process emphasis is placed on an actual description of design information in drawings. Any developments or changes are incorporated into these drawings. Therefore the origin or the history of the design can only be reconstructed from dated prints of the “original” drawings. With the aid of CAAD systems, more or less completed states of design are described as well. Just like the drawings previously mentioned, these descriptions are mainly used for the presentation of a design at the end of a design phase (Vermaas et al., 1990; Joseph, 1991). These descriptions are not yet suited, however, for the presentation of the design process that was followed. This research was initiated from the assumption that with the help of CAAD systems several design states could be recorded, and thus the design process might be partly reproduced and evaluated.

Design information is only up-to-date for a short period of time. Continuous modifications during an architectural design process, like modifications of shape, location, size, attributes, or relations of design objects, give design information a temporal character. Modifications take care of transformations or transitions of one design state into another. A design state itself is static; a series of design states, being the temporary results

of a design process, represent the dynamic state-transitions or the temporal aspects of design information (Figure 1). Design states can be recorded in different databases in such a way that the coherence between the design states is maintained. Still, certain design information may be present in more than one database, and subsequent problems such as redundant, incomplete or inconsistent information may arise.

A second cause for our research can be found in the assumption that it should be possible to store all design information in such a way that the reproduction of design states as well as the design process will be possible. This means an information-intensive information system, taking into account that reliable reproductions will only be possible if design information can be stored in one database system in a well-coordinated manner. The introduction of a time dimension and consequently the possibility of a temporal coordination, could be a great step in this direction (Hee, 1985; Rolland and Leonard, 1988).

Finally it was assumed that, if design states originate from one and the same database, it should be possible to let different design states be compared to one another. A lucid comparison of design states together with a reproduction of the design process may support the evaluation of a design and its evolution.

2  A Practical Problem: The Architectural Information Process

A consequence of the drastic fragmentation of the building industry is the fragmentation and differentiation of design information as well. Therefore the communication and consequently the transfer, interpretation, and tuning of the information play an important role during a design process. This is especially true in the building industry because the construction preparation and the construction itself are still dealt with as crafts. The transfer of information takes place with difficulty, the information on hand is interpreted loosely, and the tuning of information is unsatisfactory. The easiest thing to do is to analyze and evaluate each design individually. Comparisons with other designs are not made so it cannot be decided whether a design change is an improvement or a deterioration. Moreover, one is not able to consider the design process objectively, which might lead to a refinement or even an optimization of this process.

Research and development in the field of architectural computer applications pay explicit attention to the integration of multi-disciplinary design information during the de-
sign process (McCullough et al., 1990; Schmitt, 1992; Wagter, 1992). On international levels, as in ISO/STEP and EDIBUILD, normative work is done to achieve arrangements and standards for an integrated structure for design information (Figure 2). The work done in these groups is rather extensive and expensive, and there is a growing reserve concerning the practicality of the final results to be expected. This may serve as an illustration of the great complexity that one comes across when trying to achieve automation via systemization in the building industry. For the time being, the prospect of realizing integration of design information in the building industry seems to depend on the possibility of transforming the building trade into a building industry.

![Figure 2. Integrated structure for design information.](image)

In our view, instead of information integration, the first aim should be a conscious and further segregation of design information to allow the definition of the objects, their attributes, and their behavior to be used to build a consistent, complete, and correct design information system. This segregation is meant in regard to the different disciplines as well as to time (Figure 3). Coordination of information concerning the different disciplines can be done by a design or building information manager, or a so-called configuration manager. For this coordination it is very important to be able to determine who is responsible for what and when. The temporary and time-dependent information can be coordinated with the help of information technology. Therefore empirical research into the building information process itself is necessary. It must be determined who needs what and when. Such research needs an instrument to record processes for comparison later. Media, like video cameras, are excluded from consideration for this purpose because of “analogue” data recording. The use of computer systems for discrete “digital” registration and reproduction of different design processes is more appropriate.

For communication and coordination during the building process, complete, consistent, and correct databases should be available at certain moments. Limited or inferior definitions of the necessary contents of databases may lead to efforts to record all available data as early as possible. However, to restrict the size of databases, and avoid redundancy and mutations, it is better to record as little information as possible at a later stage. The “Just in Time principle” is also important for “Information Planning” or “Information Logistics” (Hee, 1985).

The state of a building can always be registered. How and why this state evolved is something that can only be retrieved partially, and the process is very difficult. This applies to the design process as well. Usually, much attention is paid to the presentation of a final design. One can only find a few examples explaining the design’s development; such an explanation is often based on an analysis (with some architectonic purism) after-
wards. Recording several design states might contribute to a clearer registration and better evaluation of the way a design proposal has been accomplished. Linking remarks and commentaries to these proposals, by means of temporal relations, might enhance insight into the backgrounds and motives concerning some design decisions. This might lead to more successful incorporation of empirical research into design processes and possibly to easier identification of design rules. Improvements in coaching future designers or students might be another outgrowth. A design would be more understandable and interesting if one was aware of its process through time.

Figure 3. Segregated and integrated information structure in time perspective.

3 The Research Aim: A Temporal Coordinated Information System

The aim of this research is to propose a facility to record all design information generated during an architectural design process, in a temporal coordinated manner, in one information system.

3.1 Design Information

The design information is meant to provide the kind of information that will register and reproduce design states in a declarative way, and consists of data on architectural objects in different stages of the design process. This data may have a predominant name or symbol as the identification of an object, and graphic data in coordinates describing the shape, size, and location of components constituting these objects on different levels. It may also be alphanumeric data, in attributes and operations, concerning the functionality of the objects which may be relevant for the different architectural design domains. Design states may be design versions, design variants, and design studies. Design versions succeed each other during the design process. There may be several design variants of a certain design version at the same time. To be complete, various design studies may have been made for one design variant (Figure 4). With temporal coordination, the data is meant to be ordered on the basis of aspects being temporary or time-dependent. Temporal coordination of design information creates the possibility to distinguish between retrospective, current, and prospective design information. Retrospective design information gives a review, current information deals with the up-to-date information, and prospective design information provides a preview, such as an expiration date for certain design information or a maximum application period for an object (Whitrow, 1965; Benthem, 1983; Hee, 1985).
Because of the recording of all design states, it must also be possible to register and reproduce in a procedural manner the design processes that led to these states. The design process is meant here to process a design for an architectural object in different steps and stages. By recording a number of successive design states, the design process too is implicitly, and in a more or less discrete manner, recorded in the information system. By selecting and sorting design states, the process may be reproduced again.

Such an information system should make it possible to have the computer compare different design states. For such a comparison of design states it must be possible to select the desired states first on the basis of temporal properties of the design information. After such a selection it must then be possible to at least determine for two or more design states the subtractions, intersections, and/or unions.

3.2 Temporal Coordination

To be able to select, sort, and compare different design states, knowledge should be gathered about how temporal properties can be linked to design information when being registered. For the determination of possible temporal properties, the “logic of time” or “temporal logic” can be used. Here one can find definitions and indications concerning time lines, points in time, time intervals, and time series. Time lines may for example be longitudinal (for an era) or cyclic (for a calendar). Points in time may be represented in a time dimension with the aid of time coordinates. Time intervals are comparable to certain periods, and time series are comparable to a range with points in time (Whitrow, 1965; Nauta, 1974; Whitrow, 1975; Benthem, 1983). In the domain of Informatics “time stamping,” “version control,” “event schedules,” and “time management” with “time increments” are already used for the registration of a time property while data recording (Hee, 1985). For the reproduction of a design process, one may use time intervals or time series for a representation in the form of an animation.

To be able to analyze and evaluate temporal aspects of design information, design states, and design processes, knowledge should be gathered about how calculations should be done with temporal properties. For the purpose of time calculation one can make use of time arithmetic or chronology. For the determination of a unit of measure and a unit of
account, a time dimension may be used. A time dimension is a longitudinal chain of time units. It may be employed to denote a time line and also points in time, time intervals, and time series in time coordinates. To represent time coordinates, the Julian calendar, with a time indication in days and fractions of days, may be used (Whitrow, 1972; Gumbert, 1987; Ernst, 1988).

4 The Research Problem: Temporal Aspects of Design Information

The formulation of the research problem is determined by the central issue, which is how to record temporal aspects of design information in an architectural information system.

4.1 Temporal Aspects

Temporal aspects of design information are meant here to be the aspects of this information that are temporary or restricted to a specific time. Information may:

- have the shape of a specific state (“frame”) or a transition (tween),
- be valid for a specific moment (point in time), or in a period (time interval), or periodically (time series),
- be a representation of an “instance” or “event,”
- be related to the past (retrospective), the present (current), or the future (prospective).

Time indications may be:

- absolute (clock, calendar, era) or relative (stopwatch, age),
- cosmos-dependent (sundial; location-dependent) or mechanism-dependent (clock; regional).

4.2 Design Information and Media

When recording design information the “infinity” of the volume of such information and the “finiteness” of the capacity of recording media should be taken into account (Hee, 1985). The infinity of design information is caused by the fact that the building process is not cyclic. It is a process that proceeds longitudinally. Design information for a specific site may be added continually to an information system. The finiteness of the registration media is caused by functional and technical limitations attached to several media. Although there is a constant refinement of possibilities, the capacity of the memory of computer systems is still limited. Processing possibilities are necessary to be able to make worthwhile reduction of the amount of data.

Processing possibilities to reduce the volume are:

- making a choice for one type of design state;
- making a more specific selection from design versions, design variants, or design studies, based on certain criteria; and
- making an aggregation of specific design states.
Choices and selections may be made on the basis of relevancy, age, or currency. Aggregations may yield an intersection of, or a difference between, numerous states. One can also think of other processing possibilities. A transformation resulting from a possibly automated procedure may be registered without intermediate states. The available procedure can be used again and again for any reproduction of this transformation. Through development and perhaps automation of procedures, the size of the design information system may be limited considerably. There will also be a lot of information in one design information system that will be present in other systems as well. In this case it may be better to store this information in a more general information system. Information here can be referred to from the design system, or a link can be made between this system and the general system. Of course it is also possible to make a distinction between different types of memory, such as foreground (on line) and background (off line) memory. If several media should be available for this, the retrospective information may be recorded in a background memory. The current and prospective information would in this case be stored in the so-called foreground memory.

5 The Research Framework: Architecture, Logic, and Informatics

The research framework is constituted by a combination of research domains out of the different formal and applied sciences: Informatics (Computer Science), Logic, and Architecture.

5.1 Architecture, Logic, and Informatics

The following research domains play an important role in this research for a time dimension for CAAD systems:

- Design methods within Architecture;
- Temporal logic within Logic; and
- Object- and State-oriented approach within Informatics (Figure 5).

![Figure 5. Research domains.](image-url)
Within this framework, research will be performed into design methods. The starting point here is a dependency of design levels, design domains, and design states, during design processes (ordering, integrating, and developing processes), as described in the Domains theory and the GOM-model (Bax and Trum, 1991, 1992; Trum and Bax, 1992). In this research, the need is felt for an empirical examination of the theory and the corresponding model. An adequate CAAD-system, in which design processes can be stored, will be capable to support such an examination as one of the instruments of investigation.

Research elsewhere in the field of IT in architecture is done especially in the domain of standardization, integration and communication of architectural information for all stages of the building process, and, in general, aims at multi-functional product models. One can expect to find attention for temporal aspects, design states, and design processes in Project Group P8, which, within the framework of ISO/STEP, Study Group “WG3 Product Modelling,” is going to pay attention to “Product Life Cycle Support” (Björk, 1991).

Informatics research, which is relevant for the research proposed here, deals with the object- and state-oriented approach because of the object- and state-related information. Concerning the integration of architectural information and the development of CAAD systems, the research will particularly emphasize a state-oriented approach. Because of this the research clearly distinguishes itself from research where particularly application-oriented or data-oriented approaches are stressed. A surplus value of this approach is determined by the possibility to register procedural data next to declarative data. Moreover, next to a topological ordering of components or a hierarchic ordering of objects, a temporal ordering of information will be a valuable new possibility.

It is also thought to be important to join in with research into “time management” and the possibilities of “log-files,” and “version control.” “Log-files” store the processing “history” during a design session in a data base. Version control in a data base enables the user to record different representations of entities.

![Figure 6. Intersections of research domains.](image-url)
5.2 Object, Space, and Time

Within the combination of research domains the emphasis will be put on the intersections of these domains (Figure 6). The intersections are defined to represent the following subjects:

- **Objects in design information for the registration of different states.** Because design information is considered to be a descriptive part of the architectural domain and the registration of different states is considered to be a procedural part of the Informatics domain, this subject has been placed within the intersection of architecture and informatics.

- **Space in CAAD systems to record shape, size, and location of objects.** Because CAAD systems are considered to be a descriptive part of the informatics domain and the recording of shape, size, and location of objects is considered as a procedural part of the logic (and/or mathematical) domain, this subject has been placed within the intersection of informatics and logic.

- **Time in temporal aspects for a discrete recording of processes.** Because temporal aspects are considered to be a descriptive part of the logic domain and the discrete recording of processes is considered to be a procedural part of the architectural domain, this subject has been placed within the intersection of logic and architecture.

On a longer term the core of the research will be formed by the intersection of the different intersections. This indicates a future effort to achieve complete integration of objects, space, and time, or an integral linking of the so-called fourth dimension to the three spatial dimensions of objects in CAAD systems. This would mean that shadow “moves,” concrete “hardens,” trees “grow,” and that buildings “get older” in the CAAD system. This could eventually lead to a 4-D CAAD system (Figure 7).

![Figure 7. An integration of object, space, and time.](image)

5.3 Design Systems and Design Information Technology

The current research is part of our faculty’s work in “Design Systems” and “Design Information Technology.” The following sub-research categories are of interest for the research proposed here:
• Research into “Presentation Methods and Techniques” with attention to animations (representation of changes according to a certain time series) and “virtual reality” (real-time animation for the purpose of evaluation and adaptation of virtual objects).

• Research into “Simulation Methods and Techniques” with attention to accurate and slowed down simulations of the behavior of light (DIM) and sound (SAX) in a virtual space.

• Research into “System Development Methods and Techniques” with attention to the analysis and design of procedures or routines, and dynamic, time-dependent models (state transition diagrams, graph theory), for setting down and evaluating information plans, and for prototyping.

For the purpose of joining in with the research into “Design systems,” and taking the knowledge and experience of the research team into account, the research will restrict itself to design information. Information for the benefit of construction and management of architectural objects will be left aside during this research as much as possible. Design information will be confined to functional aspects of buildings or parts of buildings. Building physics, structural aspects, and urban development situations will not be considered initially. As far as design states are concerned, the research will focus on “What” and “When” questions. Other types of questions concerning the design process, like “How” and “Why,” having to do with knowledge and rules, can or should be examined separately at a later stage.

6 The Research Questions: Descriptive, Exploring, and Testing Questions

As posed before, the primary research issue is the question how temporal aspects of design information can be set down in an architectural information system. Next to this central issue the following questions have been formulated:

• In what way can design information develop during the architectural design process?

• In what way can relations between objects, space, and time be described logically?

• In what way can temporal aspects be recorded using information technology?

Based upon these questions, several sub-questions will be dealt with. The order of these questions shows a shift of the research emphasis during the investigation. When the research is carried out, the following descriptive sub-questions will be emphasized:

• What temporal aspects are relevant to the description of architectural objects and to the recording of design information in information systems?

• What development has taken place in recent history concerning the description of the relation between objects, space, and time?

• What time indications are possible?

Next, “exploring” sub-questions will determine the main lines of the investigation:

• How can the architectural design processes be registered and reproduced beside the design states that originate from them?
• How can logical time indications be used to compare differing design states and to compute time data?
• How can different design states be registered and reproduced in an information system with the aid of information techniques?

Finally, the following predominantly “testing” sub-questions will have to yield the necessary know-how for the development of practical computer applications in which temporal aspects will be effectively implemented:

• What are the requirements for the development of architectural computer applications in order to achieve a temporal coordination of information in them?
• What is the feasibility of temporal coordination of information in specific architectural computer applications?
• What is the practicality of representative general computer programs in relation to a temporal coordination of information?

To answer the research questions, knowledge is needed from several disciplines, such as Informatics (contents and meaning of temporal information in information systems), Logic (relation between objects, space and time) and from Architecture (development of information during the building process). As yet, the starting point is that research in the different domains will for the greater part take place analogously. Architectural questions will have to be answered from Mathematics and Informatics, and any paradigms originating from Philosophy and Logic may possibly serve as metaphors when formulating architectural questions and answers.

7 The Research Results: Theory, Prototypes, and Hypotheses

The research for a time dimension for a computer-aided architectural design systems consists of the following parts:

• description of a theory,
• development of prototypes, and
• formulation of hypotheses.

7.1 Description of a Theory

This deals with research into possible indications for temporal qualities, developments concerning the relation between objects, space, and time, and temporal aspects of architectural objects, design information, and information systems. Through a critical study of literature, a normal survey, and the generalization of the findings, the formulated “descriptive” sub-questions should eventually lead to a specific or an ad hoc theory about the possibility to record all design information in an information system in a temporally coordinated manner.

7.2 Development of Prototypes

This deals with research into how design states can be registered and reproduced in database systems, how time indications can be used to compare states to compute time-related data, and how processes can be registered and reproduced. The “exploring” sub-questions should lead to a prototype of a database system through a case-study, and on the
basis of an idea about the temporal coordination of design information in information systems. The prototypes will be information systems that can be used to test and demonstrate the theory.

7.3 Formulation of Hypotheses

This deals with research into the utility of general computer programs, the feasibility of temporal coordination in architectural computer applications, and the requirements for the development of architectural computer applications. Through pre-experimental research in the form of a pilot design project, on the basis of theory and with the aid of the prototype, the “testing” sub-questions should lead to hypotheses with respect to how temporal aspects of design information can be recorded in a CAAD system.

8 Users: Researchers and System Developers

It will be possible to have the theory applied by participants in international research and development projects in the field of “product modelling.” Well-known projects in this context are: ISO/STEP, EDIBUILD c.q. EDIFACT, NOBI Practical Projects, and our own main research issue: Design Systems. It will be possible for these researchers to use the prototypes for their own presentations and demonstrations. Other researchers should also be able to use certain prototypes as research instruments for empirical research in architectural design processes. The hypotheses can be used by developers of computer-aided architectural design systems and/or computer applications for architectural practice as well as in institutes for education and research.

Theory, prototypes, and hypotheses will also be at the disposal of researchers for parallel research concerning building construction or building management instead of building design. In the case of temporal coordination of construction information, one may think of applications in the field of graphical planning techniques and logistics. Applications in the field of building documentation and information systems may be especially important for building management.

9 Final Remark

The general interest for a time dimension for CAAD systems will increase as the third spatial dimension becomes more established.

References


