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The Building Process, CAD
and the core of the architectural enterprise

by Christer Finne

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This article is a result of the author's participation in two projects on new building product models in Finland. It is an attempt to raise questions about the contradictory assumptions in a modelling system and about product model as a basis for the development of a computer-aided design system. Some demands and factors which can affect or improve the architectural design and planning processes are described.

THE RATAS PROJECT and the work done by the Product Modelling Group at the VTT have set a sound theoretical foundation for the structuring of building data in Finland. Contractors and other actors in the building process have continued the work by developing their own applications using the same context.

But the work done is based on the assumption of the existence of a product model. No one has so far told how it really emerges. The selection of a product model as a basis for systems development seemed to solve a lot of problems at the time, but who was to produce the model and when?

Another question which soon rose, was how it could be possible that statements of highly respected researchers in this field like A. Bijl:

> "The modelling system must have no inbuilt anticipations of particular perceptions of design, nor particular properties of things that may form parts of design artefacts,"[1]

or W. Mitchell:

> "There will be an increasingly urgent need to establish a demonstrably sound, comprehensive, rigourously formalized theoretical foundation upon which to base practical software development efforts,"[2]

or J. S. Gero:

> "There appear to be no satisfactory schemata available for the representation of generalised design knowledge which have the sufficient expressiveness and power. There are none which can be used to explain how a design commences or how design processes can be categorised,"[3]

could be so contradictory.

During the years 1988–91 the Laboratory of urban planning and building design of VTT has carried out a project where the structures of the Ratas Model have been developed and refined. I have had the opportunity to participate in that project as a visiting researcher and have in that capacity carried out post graduate studies in close connection with the VTT project. My work tries to find answers to the questions raised above. It started off with two assumptions; One, that the field of the architectural enterprise is so large that all the activities described above would fit in, if only the pattern was right and two, that the use of CAD is beneficial to architects. Another interesting matter would be trying to find and identify domains where the latter assumption might be less applicable.

The field of problem was structured in the following way:

1. The architect's field of activity related to CAD;
2. The core and nature of the architectural enterprise;
3. The aspect of data transfer and storage;
4. The design process and the building process;
5. The tools at hand;
6. A proposed model for an architect's CAD working environment

The architect's field of activity related to CAD

The demand for improved productivity in the construction industry

Work done at the Department of Civil Engineering, MIT, Cambridge, shows that the US construction industry has declined during recent years. The volume is flat and the investments in R&D are low. The state of the infrastructure is declining. A restoration is estimated to cost roughly 3 000 Bill. USD. The only solution seems to be a dramatic raising of the productivity within the construction industry. Such a dramatic raising can only be achieved through technological innovations. Fields for development which have been chosen as essential at MIT are:

- materials and process;
- automation and robotics and
- computers.

Consequently, an extensive use of computer based data handling is seen as the only way for the construction industry.[4] The trends seem to be alike in the European countries. The architect is in a key position when it comes to the production of building design data. Thus there is an external pressure on the architect to use CAD.

The present situation (in Finland)

There is a need for tools, both theoretical and practical, by which the development can be brought forward. Some work has been done.

The BEC and BetCad projects have improved the transfer data describing concrete elements. The Ratas project and its successors have laid a good foundation for structuring building data. This spring two big contractors, Haka and Puolimatka, have released their instructions about what data and architect should produce, and how it should be structured. The Teleratas project which was released a month ago, provides a large public database containing building information data. Accordingly there are many symbol libraries available by the building material vendors. CAD has been in use in architectural firms since the mid-80ies.

Thus, some elementary tools exist, but much remains to be done.

The role of the architect

There are many good descriptions of what architects do:

Landsdown and Maver:

> ”Architectural design is a multi-faced occupation. For its successful performance it demands a mixture of intuition, craft skills and detailed knowledge of a wide range of practical and theoretical matters. Its a cyclical process in which groups of people work towards a somewhat ill-defined goal in a series of successive approximations. (Nowadays designing a building is rarely the province of a single person.) There is no ”correct” method of designing and, although it is recognized that the process can be divided into separate phases, there is no generally accepted sequence of work that might guide design teams in the direction of achieving a satisfactory solution. The best that can be hoped for is an outcome

which satisfies the maximum number of constraints that bound the area of concern ... It is a fluid holistic process where at any stage all the major parts have to be manipulated at once."[5]

Kari Ristola:

"... In other words, architects both solve problems using different kinds of sophisticated tools and express themselves artistically."[6]

Matti K. Mäkinen:

"Finland builds in a new time on new conditions. The head of the design team is the one who realizes this. – As well the Finnish Association of Architects as its members have reasons to remember, as they wake up each morning, that the minimum size of our field of activity is the whole construction industry."[7]

The reason why so many efforts to equip the architect with appropriate CAD-tools have failed, is probably that the architect's field of action is so wide and their needs so varying. The conclusion is that the architect is

- an artist;
- an expert in technical matters;
- an administrative person.

Benefits and apprehensions

Many advantages follow with the use of CAD. Paul Teicholz has mentioned many of them[8]:

"– Reduced field labour and material cost;
- Improved constructability and operability of facilities;
- Ability to formalize knowledge in all aspects of planning, design and construction;
- Elimination of errors arising from manual re-entry of data from others input;
- Reduced rework thanks to fewer obsolete design drawings;
- Enhanced opportunities for construction automation;
- Faster and higher quality in design and construction;
- Fewer claims and arguments over extra work and changes."

Some more where listed in the Swedish Bollnäs report[9]:

- improved time coordination of the building design;
- improved drawing techniques;
- better and faster data transfer between the participants of the process;
- possibilities to produce specialized documents for a certain purpose.

As well as benefits there are fears of what the use of insufficiently tested design methods might lead to:

- the use of the program demands resources that will be taken from more important tasks;
- to manage the whole is difficult. The monitor reveals only a small part of the design at a time;
- the systems are expensive. The need for cost efficient design might influence architecture in a negative way;
- big contractors might force architects to use systems poorly fit for them which might lead to
  - limitation of possible solutions;
  - the architect has to do work which is irrelevant from his point of interest;
  - the architect has to do extra work without getting paid for it;
  - the architect might have to use improper design methods;
  - the emergence of systems for architectural design might be used by incompetent designers without proper competence.

The core and nature of the architectural enterprise

The role of the drawings

An usual misunderstanding is that architects make drawings, but drawings have tasks that go beyond the trivial ones that first come in mind. They're also

- an explicit description intended for evaluation;
- a preliminary description of how the house should be built;
- an agent for communication for the architect, with himself and with others. When an architect makes drawings he simultaneously masters a large spectrum of other design factors in a very complicated and personal way. [10]

The geometric data in drawings can have different meanings. Sometimes lines do not even refer to physical objects.[11]

The conclusion of this is that it is very difficult to penetrate the complete contents of a drawing by a computer, particularly as the contents may be partly implicit and and context bound.[12] A human being has much better possibilities to perform such a task successfully.[13]

A triangle approach

Trying to structure grasp the field of the architectural enterprise in a structured way is difficult. One approach was proposed in work done by Tong and Sririam, MIT, USA. They used a division into four[14] :

1. *Creative design alt. technology design*, where the transformation operators and the artifact space is unknown.
2. *Innovative design alt. concept design*, where the transformation operators are known, but the artifact space is unknown.
3. *Redesign*, where an existing design is modified to respond to new constraints.
4. *Routine design alt. specification implementation*, where the solution and the process that leads to it are known.

For the purposes of this work, a fruitful approach seems to be to combine the two first mentioned, and describe the architectural enterprise as a triangle, where

- creative work;
- combinatorial work;
- registering work

form its points. See figure 1

• Creative work

Traditionally there has been an impression that it's possible to collect all information concerning the design artefact, process it in a systematic way, check all possible alternative solutions, draw the logical conclusions which would be equal to the design. (The rationalistic ideology or synoptic ideal.)

This principle has showed its limitations and since the 70ties the so called neohumanistic

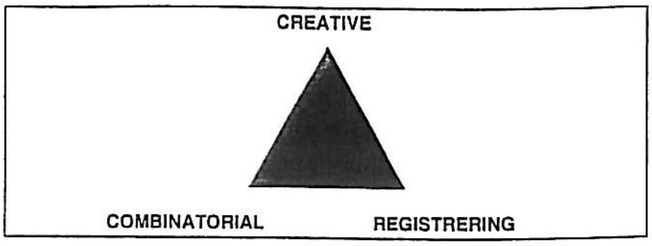

Figure 1. A description of the architect's work as a triangle with disparate aspect at its points.

ideology has gained ground. Characteristic to it is understanding design as a cyclical process of learning, together with an ambition to master the uncertain, and at the same time recognizing the presence of uncertainty and everlasting lack of knowledge. [15]

However it seems like computer sciences still had some roots in the rationalistic ideology. This leads to a certain blindness when it comes to issues like aesthetic or creative ones. There aspects where dealt with in the Finnish Essu-project.

> "Architecture becomes its existence only through a cultural context, an established praxis."

Conflicts should be dealt with using a discourse or a dialogue, not by formal rules. This leads to a demand to see computer aid as a tool instead of something that can deal with the core of architecture.[16]

However, there seems to exist matters where an approach in the rationalistic tradition is he most appropriate. According to John Archea in his paper Puzzle-making: What architects do when no one is looking[17], both are needed in building design:

> "... a distinction can be made between the protected core of the architectural enterprise (puzzle-making) and a protective shell which surrounds it (problem solving). According to this assessment puzzle-making stands as the primary service offered by the architect – an essential aspect of building that is not addressed by other professions. On the other hand, problem solving remains an unavoidable necessity when addressing the technical performance of buildings, which the architect willingly yields to other professions. – However, I sense that

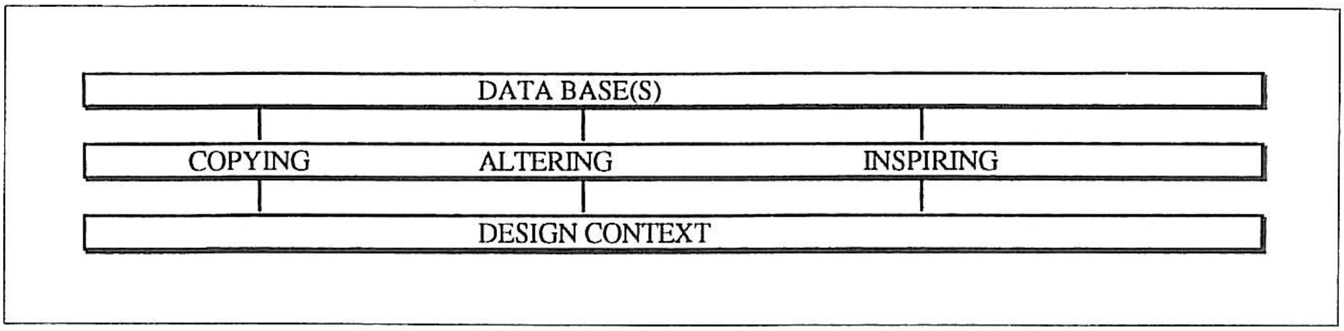

Figure 2. The use of references.

> what sets architects apart from other university educated professionals is an uncommon mode of inquiry that is extremely well suited to situations in which there is no objective way of determining what ought to be accomplished until it has been accomplished through the design process."

The important thing here is to realize that within the domain of creative work exist aspects for which existing computer tools are extremely ill suited. In certain aspects they may be impossible to implement. Still, in other aspects they are useful.

• *Combinatorial work*

The use of previous solutions are very important to the architect. The degree of usage varies from sheer inspiration to simple copying. Figure 2.

The use of existing knowledge might even be a substitute, or at least a necessary complement to the earlier described creative work

> "Though someone else may solve a problem from what you consider a fresh viewpoint it does not mean that the point was fresh from their point of view. If so, then trying to make oneself find that fresh point of view may be essentially impossible because it really means that one must transform oneself into another person, with that person's knowledge, before one can bring a new approach to that problem. But then the viewpoint would not be fresh because one had acquired all that knowledge."[18]

• *Registering work*

The task of the registering work is simply to record the result of the design decisions in an explicit way. It has to be done to make possible the earlier mentioned design evaluations. The registered work is also a media for transferring data and data storage. As a media the architect uses drawings and texts.

The aspect of data transfer and storage

Integration of design data

The aspect of data transfer and storage is not at the core of the architectural enterprise, if one limits it to what Archea called "puzzle-making". But if one wants to enclose more, like Mäkinen did, it becomes essential. It's by means of communication, of integrating design data, that the architect can master the design team.

Integration of design data can be done on several levels. One would be integrating data within the design discipline, using the same data in text and drawing documents. Another would be the use of a data base, which is common to participants in a project, doing integrated design. The third one would be the re-use of data in the various design stages.

Obstacles to integration

If design data is to be integrated, there are obstacles to be removed on many levels:

- *legislative barriers*, many design firms do still not have standard contracts or price lists for use of CAD.
- *organizational barriers*, there does not exist any stable procedures for doing integrated CAD. Everything has to be agreed upon each time separately.
- *physical compatibility*, the compatibility between the used systems needs skill and attention.

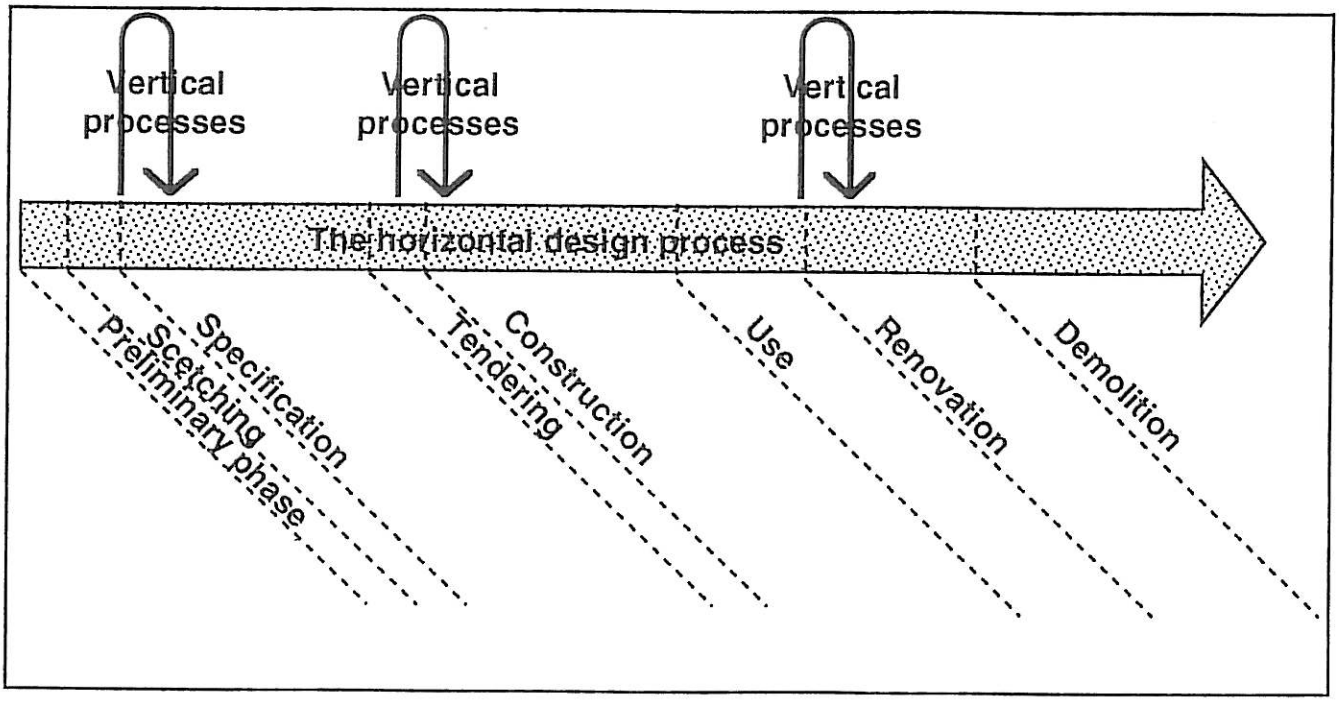

Figure 3. The design process where registering of data is illustrated as successive events and creative work as perpendicular processes

– *logical compatibility*, which is the ultimate condition for the integration of data. Here is product modelling seen as the solution for structuring building data. The work done by the VTT product modelling group shows that a product model structure can be implemented using existing tools offered by a CAD-program; symbols, layers and attributes, supplemented by word processors and database programs.[19]

The storage of data

In earlier days of CAD the general view was that common data should be stored in large consistent databases. A more present angle of approach would be to speak of distributed, loosely coupled databases.[20, 21]

The design process

The design process is often described as a time based linear process, where one design event follows the other. It starts by the definition of the basis for the contents of the design and ends at the demolition of the building.[22]

Another common method to describe the design process is to picture it as a cyclical process where one cycle of analysis – synthesis – evaluation follows the other.[23]

Either of these alternatives has its limitations and does not observe the hermeneutic nature of the design process. It seems like promising approach elaborate a bit upon a principle Swerdloff & Kalay speak of[24]:

> ”Design process requires division into higher level design operations and lower level database integrity maintenance operations. ”

and try to combine them as in figure 3 and 4.

The tools

Theories

For describing an ideal CAD environment for doing architectural design theoretical and practical tools are needed. W. Mitchell[25]:

> ”As computer-aided design grows to maturity, there will be an increasingly urgent need for a demonstrably sound, comprehensive, rigourously formalized theoretical foundation upon which to base practical software development efforts. Without this, there is ultimately no satisfactory basis for specifying system functions, for establishing performance requirements or for defining standards. Nor can we have a clear critical understanding of what we are actually doing when we design on CAD.”

Architecture theories like renaissance or deconstructivism are extremely difficult to use as a theoretical foundation for computer implementations, as they are not consistent and the interpretation of them is dependent on the user.[26]

Such programs can be built but it seems as though their output capacity will be limited. Earl Mark[27]:

> "A good topology is not only difficult to build, but imposes limitations on how a product may be used. The limits on using such a package may leave the architect with insufficient opportunity to make design manoeuvres. –, it would seem highly appropriate that the architect be put in the position of specifying the assumptions that currently are pre-conceived by the software engineer."

Amongst the theories from 'computer sciences', there are some useful tools from the point of view of this work.

Data can be represented on three levels[28]:

- *a conceptual level*, which is a logical or semantic description of the represented data.
- *a physical level*, which deals with problems which are of minor interest in this context
- *a user level*, where the user interface is defined.

The conceptual level is of special interest for several reasons. It provides the tools by which it it possible to manage data structures. These are the tools by which the earlier mentioned logical compatibility between design data is to be achieved. Direct access to the design data storage will probably be optional in CAD environments. Manual methods will also probably remain in use parallel to CAD. I therefore seems useful for architects to attain at least some knowledge in modelling buildings on a conceptual level.

Programs

For purposes of this paper computer programs have been divided into three categories.

- *Active programs*, which participate in the design process in an user-independent way. They are of a generative type who actively produce design results.

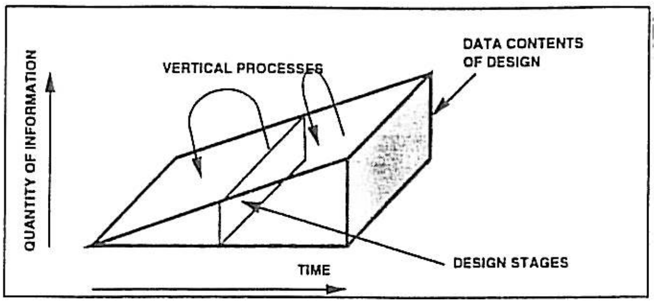

Figure 4. The relations between data contents, design phases and creative processes

- *Passive programs*, which do not directly affect the design. They are programs like drafting programs, data base programs and word processors.
- *Indifferent programs*, that have nothing to do with design. Programs like operating systems and network systems belong to this category.

Equipment

An adequate computer equipment is of course a basic condition for CAD. An extensive elaboration on this theme is, however, outside the scope of this paper.

A proposed model for an ideal CAD environment

It's scarcely possible to achieve one complete and consistent computer program by which the architect can do his work including all its subtasks. Furthermore there seems to exist aspects of his work for which no computer aid is suitable, as mentioned. It therefore seems logical to put the user, the architect, in the centre, and assume that he is the one who does the design work, and start out from the human ability to do work although the initial knowledge might be insufficient. In such a case, the role of the computer will be to assist and aid him in his work. There will be a concept, based on a **semi-automatic design process with the user in focus** and the computer aid beside him.

The model is divided into modules in order to make it easier to comprehend its connections to the design and building process. In practice there is no need for the architect to separate them. He can pass between them more or less intuitively. The modules do not necessarily correspond to

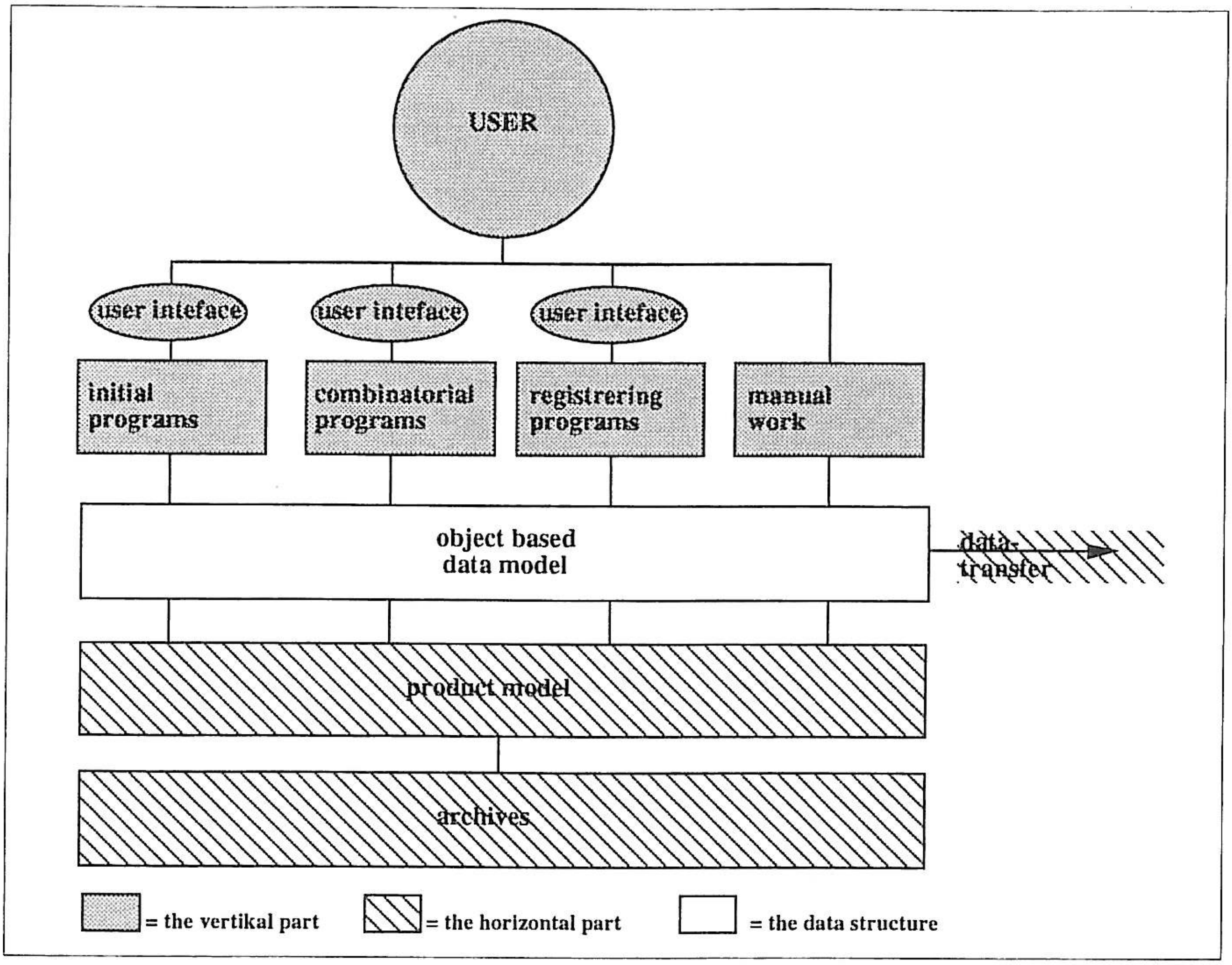

Figure 5. An ideal model of CAD and its three categories, the vertical part, the horizontal part and the data structure.

similar modules of a certain soft ware product. They mainly act as a conceptual aid to make a connection of phenomena with a mutual coherence possible. The model can also be understood as a preliminary system description for a modular combination of architectural computer aid. Yet another field where it can be utilized is as a foundation or reference for dealing with aspects of architectural design. Figure 5.

The model has three main parts the contents of which is explained below; a vertical part, a horizontal part and a data structure.

The vertical part

The vertical part includes the intuitively creative part of the architect's work, as well as other more 'customary' parts. It contains tools for design activities that initiate, accumulate and modify the contents of design.

The **role of the user** is essential. He is in charge of at least:

- communication between people;
- doing what Archea called "puzzle-making";
- to bridge over the gap between incompatible computer programs when it is meaningless to do it by a program.

In programs that perform specialized tasks and are used by trained personnel, a complicated user interface might be accepted. In an integrated environment, which spans over the whole of the architect's field of action, **the user interface** is put to a severe test. When the amount of modules increase, the use of them must be founded on a similar user interface. This is especially true in the proposed ideal environment which is based on modularity.

The role of the **initial programs** is to aid the architect in his 'inventive' or 'creative' work.

This part of the work is not a separate or isolated phase. The transfer between it and other kind of work happens rather unreflectedly. Programs that are to aid such tasks must be integrated in the total design environment that they are at hand the very moment such a design phase occurs. Programs which belong to this category are active programs such as

- solution generators;
- some expert systems;
- parts of CAD-systems;
- general brainstorming programs.

Combination programs are the ones needed to perform task which have been described as combinatorial work. Consequently, **registering programs** correspond to programs like drafting programs and word processors.

Finally the option to perform work manually, using traditional methods and tools should be taken into consideration.

The horizontal part

The tools of the horizontal part are for orchestrating the the issues raised by the time-related design process. It includes:

- tools for the physical data transfer like conversion and communication programs, various data networks and the programs and protocols that go with them;
- archiving programs;
- the physical storage of data.

It is in the horizontal part that the common database, or **product model**, resides.

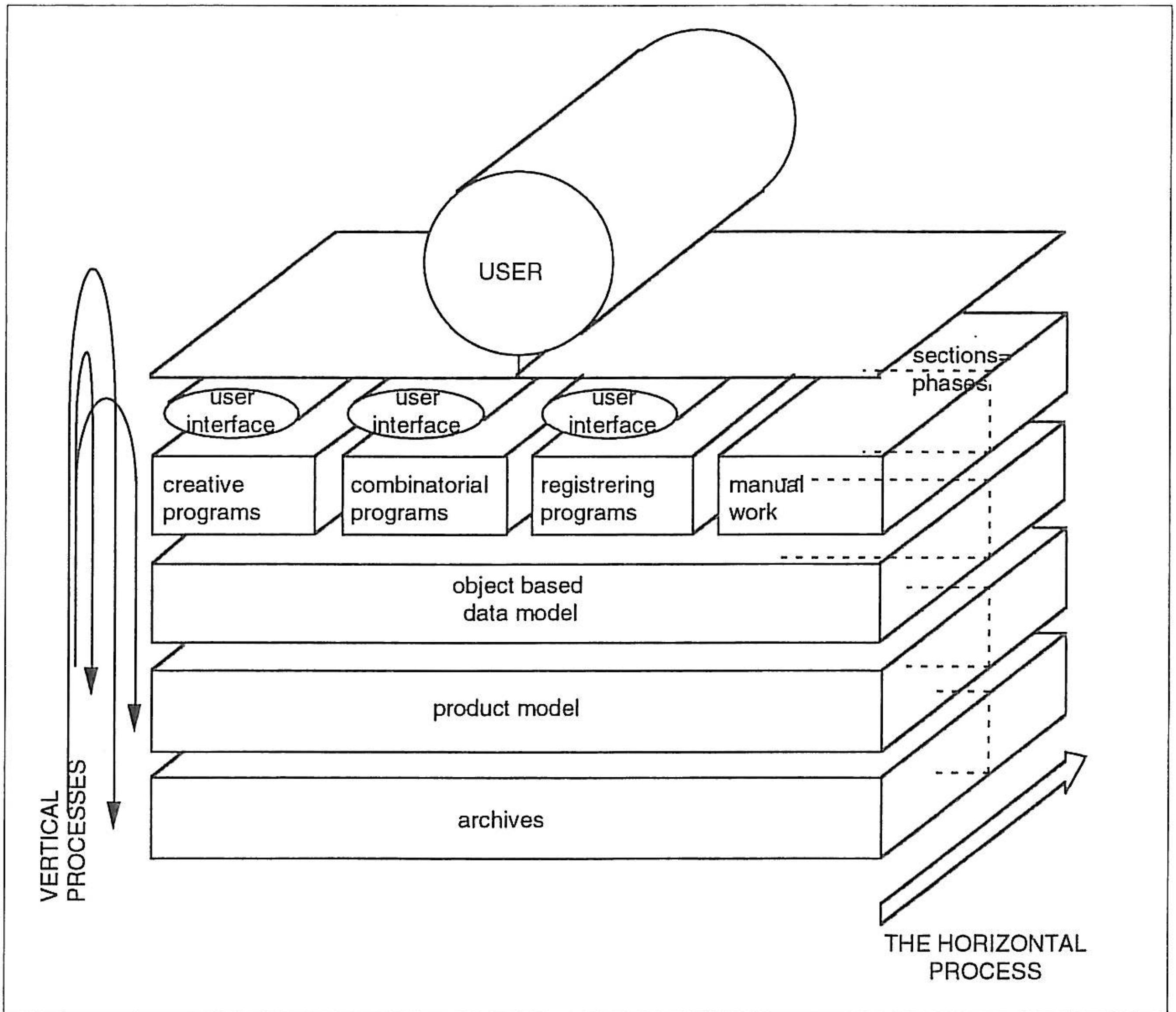

Figure 6. The all-out ideal design environment.

The data structure

The data structure is to be utilized without obstacles by the tools in the vertical and horizontal parts of the ideal environment, the modules have to be compatible. A great deal of work has been done on defining neutral formats for CAD-files. Formats like IGES, BEC and DXF are widely used. However there seems to be a trend away from storing information in separate documents towards a product model from which various documents might be generated. The future product model standard STEP has also originated from IGES. It therefore seem reasonable to assume that data in the ideal environment should be structured according to the object oriented principles of a product model. Furthermore they should, in Finland at least, follow the principles outlined by the Ratas and VTT's Product model projects.[29]

Using the modular environment

The architect ought to have access to the complete tool register that the ideal environment consists of, through the whole design process. Just at any point of time in the horizontal process, the architect should be able to perform his work as it was described above. In order to do so, he might use the ideal environment as it has been described in figure 5 in this section. The conclusion is described by figure 6 as the all-out ideal design environment.

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