A Framework for Computer-aided Reuse of Architectural Design Solutions

Hans Lindgren[1]

Abstract

Architectural design has a strong impact on issues concerning costs of operation, repair and maintenance of buildings through the selection of materials and detailing. The latter part can be described as developmental work. An important benefit of Information Technology in construction industry includes the increased possibility of reusing design solutions. In a R&D project we are working with these issues and the main purpose of our project is to investigate different methods of structuring the information related to architectural work in order to support the process of reusing design solutions. Important parts of the project are investigating the possibilities of using intelligent front-ends to support the design process and working with prototypes of the systems discussed.

Introduction

The architectural considerations concerning aesthetical issues, spatial issues, and systems design are vital to the final result of the design work. Equally important is the architects knowledge through his experience into new designs and the design work concerning detailing and the choice of materials. These considerations are not only important to the final result at the time of the construction of the building, but are also of great importance to the future use, the cost of maintenance of the building and the rebuilding that will most likely take place.

We can identify different stages in the design process from the first discussions of goal statements to the artefact specification that is the resultant of the design process. Here we are primarily interested in the stage of the design process where the main part of technical development of the artefact occurs. The main task in this part of the process is for example to specify the detailing and the choice of materials and to integrate the different solutions carried out by all the members of the design team into one working solution. Important input into this stage of design is experience from other projects. In practise, this means that design solutions very often are reused from one project to another. The word "reuse" indicates that either you can use a copy of your earlier work as it is or use it as a prototype for further development and adaptation to the new design. It is not unusual that architects develop a personal set of design solutions that you can call a construction kit or a kit of design parts which contains design solutions they have used and become familiar with.

The kit of design parts is a very important part of professional knowledge. It is not only part of a personal knowledge - in the architects office the kit of design parts becomes part of the culture of the office and in a broader sense the culture of the profession.

According to our experiences there is only very limited support in present CAD systems for the process of finding, retrieving and using design solutions carried out in earlier designs in

[1]Division of computer-aided design and visualisation, School of Architecture, Chalmers University of Technology, S-412 96 Gothenburg, Sweden, Tel: +46 31 772 23 65, Fax: +46 31 772 23 71, E-mail: lindgren@arch.chalmers.se

new designs. In respect to architectural work this becomes a serious drawback mainly because it hampers the implementation of experience into new designs.

The aim of our project is to address this problem by discussing methods which structure the descriptions of the different design solutions and the way they can be arranged within a library and to develop a prototype of a CAD system which supports this process. We are also going to use the prototype system for demonstrations.

We use an object and model-oriented approach in our prototype work using a 3D CAD program and a relational database management system to build the models and store the objects. That is an established approach in research aiming at the development of prototypes. A special interest is devoted to the design of the user interface in order to facilitate the retrieval and use of the design solutions contained in the system.

In this article I will describe the basis of the project and discuss our progress regarding the development of a prototypical CAD system intended to support the reuse of design solutions.

Design, abstraction hierarchies, professional culture and models

The basis of our project is the design which takes place in an architects office. The main reason is that we are architects ourselves and that architecture, and engineering, are considered ""prototypical" examples of design professions" [Goel 89].

Architectural design has been identified as "a multi-faceted occupation" in which "groups of people work towards a somewhat ill-defined goal in a series of successive approximations" [Landsdown 84]. Although this very simple description of the nature of design doesn't tell us more than a fraction of what can be said about design it gives us a useful sense of what it's all about. The short statement of Landsdown and Maver points to issues that we have to consider; "a multi-faceted occupation", pointing to the fact that you have to consider issues often contradictory by nature, "groups of people", implies that the need of exchange of information must be taken into account , "ill-defined goals", and "successive approximations", meaning that the CAD system we are discussing must be able to adapt itself to the different phases of the design process. The necessary adaptation of the CAD system means among other things that we must be able to work at different levels of detailing regarding the information presented to the user. If you, e.g., are working with a window you need different kinds of information about this element dependant on the phase of the design process.

The design process is not a sequential process even though it begins with goals and statements and ends with a specification of the designed artefact. When designing a building you start the process with some kind of discussion about goals and statements while at the same time you are looking for design solutions that are satisfying. Then you continue to elaborate the design in order to get a design specification including all the systems, parts and details that are necessary to create a building. A very important aspect of this process is the search for a detailed resolution of the many different problems and the integration of design solutions by different members of the design team.

The last stage of the design process is the production of final drawings, but even then you may have to refine the specifications of the design. This may be a result of technical considerations or if for some reason you reconsider the goals of the design.

Design is a question of finding alternative solutions which will meet the goals of the design. Therefore, one must ask "Does this alternative satisfy all the design criteria?" Simon 82]. The most effective method used by the architects in the search of satisfactory alternatives is sketching. Sketching is used to visualise your ideas of the design and to evaluate before they are formalised. The secret of sketching is the use of an "undetermined representation of the building" [Lundequist 89] as opposed to e.g. the very concrete representation you use when you are making the final drawing of a plan.

It is very important to note that you are sketching in all stages of the design process, not only in the beginning. A typical scenario is to discover a conflict between the design goals and corresponding design solutions concerning the detailing in a late stage of the design process. To solve those kinds of problems you have to go back to sketching as this is a method not only of finding a solution to a problem, but also to re-examine the goals of the design in question. This example also points to the fact that design is not a sequential process but rather a process in which you work with different symbolic systems responding to the current issue in order to reach a synthesis in the final design.

An other important characteristic of the design process is that you use an abstraction hierarchy in the design of the artefact. The basic idea behind this is that

> "the several components in any complex system will perform particular subfunctions that contribute to the over-all function. ... The design of each component can then be carried out with some degree of independency of the design of others, since each will affect the others largely through its function and independently of the details of the mechanisms that accomplish the function" [Simon 82].

The hierarchy used in building design typically consists of about 6 levels; the building itself and the main systems of the building are in the higher levels, and the parts and details in the lower levels. You will find that within this hierarchy the design process is not sequential although you normally start the design in the higher levels of the hierarchy. However, once engaged in the design process you do not proceed in a linear fashion but rather more freely between levels. A negotiation method is used to formally specify the design solutions at the different levels.

It is from the different levels of the design process that we must be able to find, retrieve, and use design solutions resolved in earlier designs. The conclusions we can draw from this short discussion about the design process is that we need a method that is flexible with regard to the searching hierarchy and the presentation of the results. It must be possible to search for design solutions contained in any level of the abstraction hierarchy independent of in which level you are working at that moment. The system must also be able to present the results of the find and retrieve actions in a way that is appropriate to the present needs of the designer. If, e.g., you are sketching you need less detailed information about a window than if your are working with detailed drawings of a facade.

According to Gero and Rosenman [Gero 90] "designers must have some prior knowledge of the objects and concepts which they will manipulate". This knowledge is developed in praxis and after some years of professional design you have created a set of design solutions and learnt how to use them in different situations. If, for example, you are working with architectural detailing, the different solutions of the details represent your knowledge of detailing in architecture. This is to say that the process of acquiring knowledge and the process of design are, within this context, different perspectives of the same process.

This set of design solutions are used as a kind of kit of design parts by the individual designer. This kit quickly becomes an important aspect of the culture of the architects office. In this respect the knowledge of an architect is closely related to the culture of the office.

An essential part of the professional knowledge of an architect is the ability to use models. The concept of modelling and the use of models may be very complex in the conceptual and theoretical sense but praxis develops at least a professional understanding of the use of models in building design. In fact if you want to become an architect it is an important part of the educational training to learn how to work with different models of buildings.

In traditional practise the architect uses models such as "Drawings/plans", "Sketches", Perspectives/views", "Models" (i. e. scale models), "Animation" and "Simulation" Lundequist 89] as a representation of the design artefact. When CAD was introduced to the architects the applications were design to imitate the traditional way of representation of the design object. In terms of models you can say that in spite of the new technology brought to the architects they continued to work with virtually the same set of models. I think that the main reason for this is the professional culture and of course there are also very practical reasons such as the major limitations of computers and software used during the last decade. CAD packages running on personal computers did not support true 3D graphics when they were introduced to the market and there were limitations regarding the operating systems and processing power. Larger systems were suffering from other problems such as very high costs and man/machine interfaces that were very difficult to handle.

The present development of software and hardware has put an end to many of those problems and there is a growing interest in using 3D modelling technology. The 3D modelling approach to CAD systems has the potential to provide more appropriate support to the design process than draft oriented 2D CAD systems. This is due to the fact that the 3D model oriented systems focus on a model of the building that is more universally useful than drawings. You can even argue that the traditional drawings of the building are of a very limited interest, being primarily a product necessary in the construction process. The 3D model concept means that you build a model of the building that integrates the various models described earlier into one single model which you can use for different purposes such as design, production, maintenance, rebuilding and destruction. As for the architects the 3D modelling technology is a very important step towards an integrated design environment.

It is interesting to note that today there is a tendency to replace real world laboratory experiments with virtual reality experiments at the schools of architecture using 3D models as a basis for the experiments. Virtual reality experiments are used not only for simulations in structural and building design but also in order to teach the students concepts such as spatial design.

We believe that an extended use of 3D models is a good means of raising the quality of architectural design. On the other hand it is an evolutionary change in the professional knowledge of designers which in the long run will change the professional culture more completely than the traditional CAD systems did. This is due to the fact that, "In the foreseeable future the architects design work is going to co-exist on two cognitive levels; the architect will have to learn how to master CAD technologies, and he will still have to master traditional methods of design. But these two levels of cognition are mutually interdependent..." [Lundequist 89]. The interdependency means that traditional design methods and CAD methods will influence each other and in a decade or so you will notice important changes in both manual and computer-aided design.

You should expect, however, to meet many problems along the way and we think that one of the most important questions concerning the extended use of models is the relation between the model and the real world. Brian Cantwell Smith has discussed this issue in a panel session at the 1985 International Joint conference on Artificial Intelligence in Los Angeles and the basis of the question is the use of models when designing computer systems. According to Smith, models can be viewed as being between the computer system and the real world, which the computer system is intended to be about. The problem is that we do have a theory of "the relationship between so-called formal systems ... and the model", and "we don't have a theory of how well representational systems perform, in the sense of taking actions" [Smith 89].

Obviously this question is apparent even when you are using models in computer-aided architectural design and the introduction of 3D modelling technology will make this problem even more apparent. I agree with Lundequist and Kjelldahl [Lundequist 89] when they say that;

> "An interesting feature of the facilities above is that they use 3D. Three dimensional work was used by architects for a long time but started to disappear during the beginning of the twentieth century. With computers, we might see the return of three dimensional models."

We can conclude that 3D modelling technology will give the architects one of the most fascinating and important tools ever and that, undoubtedly, it will turn out to be a very important contribution to the development of the culture of the architects profession.

Computer modelling and design

When you are working with traditional methods of design the drawing is a kind of collection of object instances, e.g. columns and beams, rooms, windows, and doors forming the model of the building. When the project is finished most of the drawings are stored in an archive which is an important part of the architects office as a warehouse for knowledge and experience. The drawings are classified according to the name of the project and there is no classification of the drawings with regard to the contents in terms of for example parts and details.

In another archive you may have product information from a manufacturer concerning e.g. different systems, parts, and details that is structured according to the SfB classification system.

Using current CAD systems is similar to using traditional methods, the only difference is that when using CAD systems you can use applications that support the retrieval of the different drawings. There is, however, no support that will let you find different details contained in the drawings or, in terms of conceptual modelling, different object instances in the sub levels representing e.g. the subsystems and the parts in the model of the building.

To enable the designer to make extensive use of a library of design solutions containing e.g. the different parts of a building, it is necessary to define a method to retrieve the objects which is an integrated part of the design system. One way of doing this would be to use a conceptual model of a building as a generic structure for the descriptions of the different design solutions and to base the arrangement within the library upon this. There is still no standardised building product model that we can use but there is a lot of research focused on developing theories of modelling and product models.

An important contribution to the discussion of building product modelling is found in Björk [Björk 89a], Björk and Penttilä [Björk 89c] and Karstila, Björk and Hannus [Karstila 91]. As a result of a large R&D effort in Finland a basic structure of a building product model has been developed. "The model is conceptual, using concepts such as objects, attributes, and different types of relations between objects. The model is capable of containing all kinds of data describing a particular building." [Björk, 89a]. The model is known as the RATAS model and consists of objects organised in an abstraction hierarchy, attributes, classes, and relations. The abstraction hierarchy consists of five levels: building, system, subsystem, part, and detail (Ibid.).

The RATAS model has been used in prototype development described by Björk and Penttilä [Björk 91c]. Of special interest to our project is the fourth prototype that consists of a CAD system (Intergraph's Microstation), a RDBMS (Oracle), and a hypermedia development package (Supercard). In other articles Björk has discussed "Product models of buildings and their relevance to building simulation" [Björk 89b] and "Intelligent front-ends and product models" [Björk 91a]. The publications give a broad view of product models and their use in building design but as Björk mentions "The interplay between the building product model and the design process also needs to be studied" [Björk 89a].

In Sweden the development of product models have taken another direction. We have a strong tradition of using classification systems within the construction industry mainly in order to organise the information of resources and building parts used in the construction process. The first attempts to use a systematic approach to classification in the construction industry were made in the 1930s and the efforts resulted in the SfB system that was published 1950. This system was developed as a complement to the UDC system and became internationally accepted. A classification system adapted to modern construction methods were developed using the SfB system as a basis. This system was published in 1972 and is called the BSAB system.

Today this system plays a very important role in the classification of the information of resources and building parts in the construction process and lately it has been proposed as a product model for computer modelling of buildings in Sweden (Neutral byggproduktmodell - systembeskrivning, 1991).

We have tried to analyse the design process in relation to conceptual modelling to see in what way we can use the information structure of the conceptual model of the building in the different stages of the design process. If we continue to stick to our simplified picture of the design process we can conclude that in the initial stages of the process, when you are working with an undetermined representation of the building, the information concerning dimensions and other details is not relevant or even desirable. When, on the other hand, you are working with the elaboration of the design, dimensions may be one of the most important pieces of information needed.

A conclusion by Björk [Björk 91b] is that "Objects from the higher levels in the abstraction hierarchy are especially useful in early design stages.". Considering, however, that sketching is a vital contribution to the problem solving even in the late stages of the design process we must be able to use the objects from the higher levels of the abstraction hierarchy in the entire design process. In other words you need access to the information that is relevant to sketching in all stages of the design process. When you are elaborating your initial sketches we believe that the objects belonging to the middle and lower levels of the abstraction hierarchy are the most frequent objects. In this part of the design process you need access to detailed information as well.

From the point of view of the sketching that is part of the late stages of the design process access to the objects belonging to the middle and lower levels of the abstraction hierarchy will possibly increase the quality of the work. When, e.g., we find an object belonging to the part level of the abstraction hierarchy and use it in sketching the system will only present information that is most relevant with respect to sketching. At the same time it is fairly easy to allow the user to alternate between different views of the information. By doing this he can reach the whole amount of information that is available about the object if or when needed.

We believe that this is true even for the sketching in the early stages of the design process. However, in this phase there is more research necessary in order to find the relationship between the informal method of sketching that is a strong tradition in the architects profession and the formal rules that are part of a computer system.

To summarise what I just have said I will argue that in any stage of the design process we need different views of the objects from all levels of the abstraction hierarchy with respect to the information presented to the designer.

Independent of which stage of the design process that you are working in and in which level of the abstraction hierarchy, it must be possible to find and retrieve all kinds of information about the building. This can be obtained if you use a graphical representation of the abstraction hierarchy, preferably in the form of a tree structure. By, e.g., clicking on the desired node in the structure you can activate the procedure of finding and retrieving the information that corresponds to the node. The system will present you with a list of alternative solutions concerning that specific part of the structure and once you have made your choices it will send a SQL-query to the database and retrieve the possible answers

You can compare this method with a CASE system that includes a graphical modelling tool that you can use in database design. Once you have made a graphical model of the entities and relations of entities which you need a database to manage, the CASE system will generate a SQL-code that you can use to set-up the database tables.

User interface considerations

The key module in the CAD system we are discussing is an interface that will integrate the other modules of the system. McCullough [McCullough 90] discusses integration issues pointing to vertical and horizontal integration as two directions of integration. Vertical integration means "the integration of models and applications within a given CAD system" and horizontal "the flow of information between different task domains to facilitate the sharing of information between other designers (and users) who are contributing to the design process" (Ibid.).

We are considering an expert system shell as a means of building the interface and to integrate in the first place the CAD program and the database. In this context the expert system shell performs the vertical integration and you can use it to set-up the design environment and to aid in the retrieval of design solutions. The system can also be used as a guide for the user of the design system and provide the proper tools once the user has identified himself to the system.

It is equally important that the user can adapt the system to changes in the need of information that may occur during the design process. We suggest the use of an expert system shell even for this purpose.

The horizontal integration is an equally important issue. McCullough says that "it will certainly cause changing roles within industries...to change the role of the architect to one of greater involvement with a building throughout its entire lifetime" [McCullough 90].

The background is the fact that architectural design is a group activity including many professions and many people, each with his part of the job and an individual need of information. The development of computer networking technology will no doubt facilitate an integrated project environment that will suite the needs of the consultants. However, once you adopt the 3D modelling approach, you need a method to filter the information presented to the individual user of the CAD system. This is because a 3D model of a building contains all the information that is dispersed on many models when you use traditional methods and that it is very confusing to be forced to take part of information that is not relevant with respect to your activities.

In a paper on models in computer-aided architectural design work Lundequist and Kjelldahl say that "The designers professional knowledge consists - partly - of a set of <u>mental models</u> that represent a set of "typical cases" derived from previous design work practice". These mental models consists of "a "description"... of a typical... work situation, and a "prescription" of which <u>rules</u> to follow in a similar situation" [Lundequist 89].

The ideas of typical cases, typical work situation, and prescription of rules indicate the use of knowledge-based systems in order to integrate the computer design environment and filter the information presented to the user. The use of knowledge-based systems in this respect is also indicated in McCullough [McCullough 90] that is a brief overview of issues in intelligent CAD including among other things discussions on integration issues, partial and approximate information, user interfaces, and the terminology within the AI community. A further reference is McCullough [McCullough 91] that is a discussion on knowledge representation issues in computer-aided architectural design.

The prototype set-up

An important purpose of our project is to develop a prototype of the CAD system we are discussing. In order to do that we have set up a laboratory environment consisting of a UNIX workstation running a 3D modelling CAD system and a relational database management system. In the next phase of the prototype development we are adding an expert system shell. The system is connected to a networking environment including X-terminals and PCs.

Conclusions

The proposed CAD system addresses an important part of architectural design - the work carried out to elaborate the design - and the team work that is crucial in the design process. These issues are critical with respect to the quality of the design work and the emerging of CAD systems that support these issues will, in the long run, provide for a change of the pattern of work and in the culture of the architects office. You need, however, a starting point for the evolution where you can recognise your present situation in the new way of working with respect to e.g. the selection of metaphors and the design of user interfaces.

An important issue is that the approach we have chosen for the proposed computer-aided design system will make it possible to integrate the system in a framework for the overall information management in a construction project as discussed by Björk [Björk 91b].

The design system will, above all, promote a systematic approach in the development of new designs with respect to the reuse of design solutions and the integration of an architects knowledge through his experience into new designs. This will give us considerably improved possibilities to strengthen the quality issues in architectural design.

References

[Björk 89a] Björk, B-C , "Basic structure of a proposed building product model", in *Computer-Aided Design*, Vol. 21, Number 2, March 1989.

[Björk 89b] Björk, B-C , "Product models of buildings and their relevance to building simulation", in *Building Simulation '89 Conference proceedings, Vancouver, Canada, 23-24.6.1989*, International Building Performance Simulation Association, pp. 193-198.1989

[Björk 91a] Björk, Bo-Christer , "Intelligent Front-Ends and product models", in *Artificial Intelligence in Engineering*, 1991, Vol. 6, No 1.

[Björk 91b] Björk, Bo-Christer , "A Unified Approach for Modelling Construction Information", in *Building and Environment*, 1991/92

[Björk 89c] Björk, Bo-Christer; Penttilä Hannu , "A scenario for the development and implementation of a building product model standard", in *Adv. Eng. Software*, Vol. 11, No. 4, 1989.

[Björk 91c] Björk, Bo-Christer; Penttilä Hannu , "Building Product Data Modelling - Experiences of Prototype Development", Draft paper submitted to *Microcomputers in Civil Engineering.*, 1991

[Gero 90] Gero, J. S.; Rosenman, M. A., "A conceptual framework for knowledge-based design research at Sydney University's design computing unit" in *Artificial Intelligence and Engineering*, 1990, Vol. 5, No. 2, 65-77.

[Goel 89] Goel, Vinod; Pirolli, Peter , "Motivating the Notion of Generic Design within Information-Processing Theory: The Design Problem Space" in *AI Magazine*, Spring 1989, 18-36.

[Karstila 91] Karstila Kari; Björk, Bo-Christer; Hannus Matti, "A conceptual framework for design and construction information", *First International Symposium on Building Systems Automation-Integration*, June 2-8 1991, Madison, Wisconsin, USA.

[Landsdown 84] Landsdown, John; Maver, Tom, "CAD in architecture and building" in *Computer-Aided Design*, volume 16, number 3, May 1984, 148-154.

[Lundequist 89] Lundequist, Jerker; Kjelldahl, Lars , "Models in computer-aided architectural design work", in *Acta Polytechnica Scandinavia, Civil Engineering and Building Construction Series No. 92*, Helsinki, 1989.

[McCullough 90] McCullough, Jonathan (1990), "Issues in intelligent CAD", in *Intelligent CAD, II*, Eds. Yoshikawa, H.; Holden, T., Proceedings of the IFIP TC 5/WG 5.2 Second Workshop on Intelligent CAD, Cambridge, United Kingdom, 19-22 September, 1988.

[McCullough 91] McCullough, Jonathan (1991), *Knowledge based systems in architecture*, Document D10:1991, Swedish Council for Building Research, Stockholm.

[NBPM] Neutral byggproduktmodell - systembeskrivning [Neutral Building Product Model - Description of the System Design, (the translation of the title has been made by the author of this paper)] (1990), Byggnadsstyrelsens informationer T:123, 1990, Stockholm./No English summary/

[Simon 82] Simon, Herbert A. (1982), *The Sciences of the Artificial*, 2d ed. Cambridge, Mass., MIT Press.

[Smith 89] Smith, Brian Cantwell , Smith's Presentation in "Expert Systems: How Far Can They Go?" Ed. Davis, Randall, in AI Magazine, Summer 1989, 65-68., 1989