



**KTH Numerical Analysis  
and Computer Science**

# **Building the Building – Changes to the Construction Process through New Use of IT**

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# Abstract

## Building the building – Changes to the construction process through new use of IT

The building industry in Sweden is currently in a state of change. Efforts are made developing new tools and work methods in order to improve efficiency and quality in the work process. The work is performed under the project "IT – Bygg och Fastighet 2002".

These changes in the work process involves implementing the standard IFC (Industry Foundation Classes) which is a standard for 3D modelled construction plans that can replace the traditional line-based drawings. The changes also involve a new way to communicate and coordinate work in a project. By letting all participants of the process work directly towards the same data, efficiency of the process can increase. Overall it can be said, that a new work process being developed, the cooperative process.

This thesis tries to examine this new process from the perspective of CSCW (Computer Supported Cooperative Work) and set out to find out who will gain and who will lose on the introduction of the cooperative process. The new process will most likely fail unless it does not aid, and consider the effects it has on, the people working in the industry.

The new process will likely be fully implemented, but it will take time. Many of the problems with the new process are actually problems switching to the process, not problems with the process itself. The Business models that are used must for instance be updated along the other changes.

# Sammanfattning

## Att bygga byggnaden – Förändringar av konstruktionsprocessen genom nya tillämpningar av IT

Byggnadsindustrin i Sverige befinner sig i förändring. Mycket arbete läggs just nu på att utveckla nya verktyg och arbetssätt för att öka effektivitet och kvalitet i arbetsprocessen. Arbetet görs under projektet "IT – Bygg och Fastighet 2002".

Dessa förändringar i arbetsprocessen innefattar att implementera standarden IFC (Industry Foundation Classes) vilket är en standard för 3D-modellerade konstruktionsritningar som kan ersätta traditionella linjebaserade ritningar. Förändringarna innefattar också ett nytt sätt att kommunicera och koordinera arbetet i ett projekt. Genom att låta alla processens deltagare arbeta direkt mot samma data, kan processens effektivitet öka. Sammanfattningsvis kan man säga, att en ny process utvecklas, den samverkande processen.

Denna rapport försöker undersöka denna nya process från ett CSCW (Computer Supported Cooperative Work) perspektiv, samt försöker hitta vem som vinner och förlorar på införandet av den samverkande processen. Den nya processen kommer förmodligen att misslyckas om den inte hjälper, samt tar hänsyn till de effekter den har på, de personer som arbetar i industrin.

Den nya processen kommer sannolikt att införas fullt ut, men det kommer att ta tid. Många av problemen med den nya processen är i själva verket problem att byta till processen, och inte problem med processen själv. Affärsmodellerna som används måste till exempel uppdateras med övriga förändringar.

## Table of contents

Executive summary .....	1
Introduction .....	3
Background – The process of building a building .....	5
The phases of the building process .....	5
Project management .....	6
Participants of a project .....	8
The customer .....	8
The architect .....	9
The engineers .....	9
The construction workers .....	10
The manufacturers of building material .....	11
The building managers .....	11
Cooperation in a project .....	12
Problems for the industry .....	12
Limited perspectives .....	12
Incompatible software systems .....	13
Incompatible data formats .....	13
Double work .....	14
Collision in plans .....	14
Experiences from earlier projects .....	14
Novice customers .....	14
Poor calculations on material usage .....	15
Poorly updated reference models .....	15
Poorly adapted software systems .....	15
Summary .....	15
IT in the building process .....	15
Goal and means of ITBoF .....	16
Project results .....	16
Sub projects .....	17
IFC .....	17
A product model .....	17
3D models instead of lines .....	18
Online document handling .....	18
Workflow based on IFC .....	19
Reference models .....	20
The importance of IFC .....	20
Implementing IFC .....	21
Compatibility .....	21
Versions of IFC .....	21
Other applications of IFC .....	21
Theory – User orientation and IT .....	23
CSCW .....	23

HCI – Origin of CSCW .....	23
HCI .....	24
History of HCI .....	24
Methods of HCI .....	25
Parallel design .....	25
Prototyping .....	25
Identifying the users .....	26
Consistency .....	26
Benefits of HCI .....	27
Challenges for HCI .....	28
Differences between HCI and CSCW .....	28
Methods of CSCW .....	28
Ethnographical study .....	29
Contextual inquiry .....	29
Types of cooperation .....	29
Asynchronous or synchronous communication .....	30
One site or multiple sites .....	30
Shared information space .....	30
Method – Learning the industry .....	33
Interviews .....	33
Who was interviewed? .....	33
Alternatives to interviews .....	33
Questionnaires .....	34
Contextual inquiry .....	34
Literature .....	34
IT-Barometern .....	35
Results .....	37
The cooperative process .....	37
Computer security .....	39
The industry today .....	39
Computer supported work .....	40
IFC situation .....	40
Architects .....	41
Engineers .....	41
Material manufacturers .....	42
Building managers .....	42
Discussion – Effects of the new process .....	43
3D instead of 2D .....	43
User testing .....	44
Flexibility within the standard .....	44
Supporting the users in communication .....	45
Responsibilities .....	45
Other industries .....	46
Problems with an open format .....	47

What problems could be solved? .....	47
Building element databases .....	48
Empirical work .....	48
Simultaneous work .....	48
Sequential work .....	49
Semi parallel work .....	49
Problems with Implementation of the new process .....	50
Five factors .....	50
New technology .....	51
Responsibility for the database .....	52
The need of education and training .....	52
Lack of formal education .....	52
Economic savings in projects .....	53
The architects .....	53
The engineers .....	53
The material manufacturers .....	53
Calculations of material usage .....	54
Fewer errors in construction .....	54
Conclusions .....	55
Introduction of changes .....	55
Business models .....	56
Information regarding the changes .....	57
Who loses on the new process? .....	57
Recommendations – How to implement IFC .....	59
Guidelines for architects and engineers .....	59
Guidelines for building managers .....	60
Guidelines for customers .....	60
Future directions .....	61
References .....	63
Appendix A – Technical Terms .....	65

## Executive summary

The construction industry in Sweden is about to change. On an initiative of the industry itself, a five-year research project has just been completed: a project intended to develop new methods and tools for the industry. In fact this will change the work process for the industry profoundly. This new process I have decided to call the cooperate process.

Did the project succeed? – Well, it is yet too soon to tell. Time will tell if the methods and changes to the construction process proposed by the project will be implemented by the industry. This is an attempt to evaluate its proposal; to examine the new work process from a different perspective. The project was named IT Building & Real Estate 2002 (“IT Bygg och Fastighet 2002”), referred to as ITBOF) and tried to find new ways of work by closer integration and information sharing between the participants of the building process. This is done by introducing new IT standards and tools. One of the main parts of the new way of work is an international standard called IFC (Industry Foundation Classes). Originally an American initiative, the organisation behind IFC, IAI (International Alliance for Interoperability) now has chapters all over the world.

IFC is best described as a product model for buildings. This means a computerised model of the building; from the first steps in the planning phase, through the entire managing phase until deconstruction. The model will replace traditional paper based drawings, both when constructing the building as well as when managing it. All people who at some point work with the plans of the building, either the original construction plans or the reference model, will work with this model. Information is shared between the participants.

IFC is based on ISO standards and is believed to solve several of the industry’s problems. IFC is a non-proprietary infrastructure for communicating between software applications. The very basis of the standard is its openness; there will be many different applications from different software companies available, and all of them will be able to communicate. This allows different participants of the building process to communicate directly with one another, regardless of what software they are using. IFC also allows all participants to work towards a shared digital space; when one person makes a change in the building all other participants can immediately see it. All of this is expected to make the process much more efficient and significantly reduce the number of errors.

How much will this change the way we work? Well, it naturally depends on how one works today. All IFC compatible software requires modelling in 3D. Some people already work in 3D today, and for them the step is a minor one. Those who work with pen and paper will have more to learn. There is a great need in the industry, not only for education and training, but also investments before this vision can be reality.

What are the effects of the changes? The biggest gain is in the efficiency of the entire process is improved. Shorter planning times, fewer errors, better calculation on material usage, standardised documentation of projects, reference models integrated with document handling systems, remote accessible reference models and the possibility to fully communicate electronically are the primary positive effects. The negative would be the great need of education, the time it will take to learn and adapt to the new process, need for new investments and of course the possibility of the process failing.

Who gains and who loses on this? It is hard to say who will gain on this, as it depends on how the business models are changed along with the process. Most likely the process is more efficient so the customers could gain on this. For individual engineers or architects it could mean faster work with 3D CAD (Computer Aided Design) and fewer errors in drawings; overall higher quality and better possibilities to guarantee quality. For building managers it will lead to a need for a new reference model handling system, possibly the last one they will ever need. All data can be stored in an ISO standardised format that can be read in the future as well.





## Introduction

The construction industry is one of the oldest industries that still remain in today's society. For many hundreds and even thousands of years, man has constructed houses and buildings for various reasons. Some buildings were built for protection, some for housing, some as industrial buildings and some as symbols of power and knowledge. When the Egyptians built the pyramids, they had roughly the same needs as the construction industry of today has. Of course both building methods and regulations regarding worker security has changed since then, but the basics of the process does not differ that much. It is still about planning the building, acquiring the material needed, constructing it according to the plans and then maintaining the building during its life span.

During the thousands of years that have passed since the pyramids were erected the construction process has slowly evolved. As soon as new materials become available they are incorporated in to the process and whenever architects and engineers learn how to make better calculations, new methods of using the materials evolves.

Buildings are special in our society. They live longer than anything else around us. There are buildings that are hundreds of years old, still being used today. These buildings are not always used for what their architect originally had planned for, since the needs of society have changed. Of course most churches are used exactly the same way as it was planned, but many industrial buildings are today used as residents or commercial spaces. Many buildings manage to outlast both their architect and his or her intention.

The construction process is still not finished. Changes to it are always on the way. In the early nineteen eighties micro computers were introduced at a more reasonable price than before and the industry started to shift towards use of technologies such as CAD. The computers also changed the process, and still are. The next big change is a dramatic change when trying to realise the vision of integrated CAD. The vision has been around as long as CAD but not until now has computers and computer communication been able to support it.

The initiative to make these changes is taken by the industry itself, in order to make the process more efficient and optimised. Today computers are just another tool for the industry in the same way as the most classical architectural tool, the drawing board. Computers cannot yet replace the designers and will surely not be able to do so for a long time, if ever.

This thesis investigates the latest changes in the process and is written in the perspective of CSCW (Computer Supported Cooperative Work, explained further on). Therefore it is supposed to be read by those without knowledge in the construction industry and its processes. Many things are simplified simply because the points made do not require any deeper knowledge of the industry and examples are kept simple and easy to relate to. In order for the thesis to be of any use for people in the construction industry, CSCW and its background are also explained, this section is also simplified.

The thesis tries to look at the changes of the process in the light of CSCW, but it is impossible only to look at one side of things. Many of the points I try to make are not in any way related to CSCW but they simply have to be made when evaluating the process as a whole.

Finally this thesis cannot take all aspects into consideration. Legal aspects are for instance not at all covered. It also does not go deep into the roles of the process' participants; it is more of a general character.



## Background – The process of building a building

The construction industry is a complex industry made up of many different companies in various lines of business. These include many vastly different competences such as carpenters, crane operators and electricians but also architects and engineers. Their respective fields of expertise span great areas covering every possible aspect of building a building. Their methods are constantly being improved to make them more efficient, less money consuming and more friendly to the environment.

Approximately 94 percent of all Swedish entrepreneur companies employ less than 10 people. Among architects the number is even higher [Andersson, Ekholm '03]. The industry consists of many small, or even very small, companies and this has a significant impact on the methods and processes of the industry.

Smaller companies naturally lack some of the possibilities and limitations large corporations have. Larger corporations can more easily support non-core competences within the corporation. Functions as specialists and IT-support personnel are almost exclusively found in larger corporations. They can of course be outsourced and therefore used by the smaller ones too, but it is still not as common. Since the industry is rather small it is difficult to acquire computer tools adapted to the industries needs in the same extent as some people in the industry would like too. The industry and therefore the potential software market is simply too small.

Differences in companies of different sizes can be found in many reports. In IT-Barometern, [Samuelson '98, Samuelson '01A] two surveys of the computer use in the construction industry, all question with answers grouped after company size clearly show this difference. In the report Computers in Practice [Richard Coyne et al. '96] it is said that this difference also comes from the fact that smaller firms take a different kind of jobs. Smaller firms tend to work more with design issues where work is more based on hand drawn sketches and drafts. This will also influence the computer use of these firms, since sketching and designing tends to be easier made by hand.

The process of constructing a building has developed over a very long time. Some parts of today's process are remainders from older times, but most aspects have been updated, adjusted to how the world has changed around it. The essentials have not changed much lately though – the process has been almost static for many years. The introduction of computers has naturally changed a few things, but the changes are small: Computers make calculations of structure strength instead of someone doing it manually and so on; this is nothing more than a change of tools. These changes have come slowly, some people still work the same way it was done 30 years ago while others work with advanced computer tools. 23 percent of the time spent by architects on making plans is still today spent drawing by hand [Samuelson '01A].

The building process can be seen as two separated flows; one flow of information and one of materials and components. This thesis focuses only on the information flow part, and how the participants work together, primarily in the planning phase; emphasising on 3D CAD (primarily IFC based software) and the impact it will have on the industry.

### The phases of the building process

It is commonly said that there are four phases of the process. These are planning, purchasing, production, and managing (see fig.1).



Fig. 1, Phases of the building process

In the planning phase all plans are laid. All aspects of the building are planned and decided. The drawings and descriptions are made and the phase produces a description on how to build the building, what materials to use and how to build it. It is in this phase the architect and the engineers mostly work.

In the purchasing phase all material and all the components are purchased. The planning phase results in many documents and these are compiled in this phase to see how much material is needed. This can be a surprisingly complex phase in larger projects. Today much of this work is done manually.

In the production phase the building is actually erected. It is also a complex process that is dependent on several factors and involves many people with many different competences. This part of the process will not be investigated at all. The people who work in this phase are users of information and do not produce it. This sub process will most likely change due to the changes in the planning phase but it is futile to try to investigate this until the changes in the planning phase are complete. To many loose ends still remain.

The final phase is also the longest phase. Once the building is finished and inspected the managing phase begins. This phase stretches on for the entire life span of the building. During the lifetime of a building it will most likely be rebuilt and modernised several times.

## Project management

There are several different legal forms a project can take. These are carefully regulated in various standardised contracts. They fill the need of distributing responsibilities between the participants, which is important if something goes wrong. All responsibilities have to be clear at all times. In reality it is not always so and there can be quite problematic to make someone take responsibility for an error.

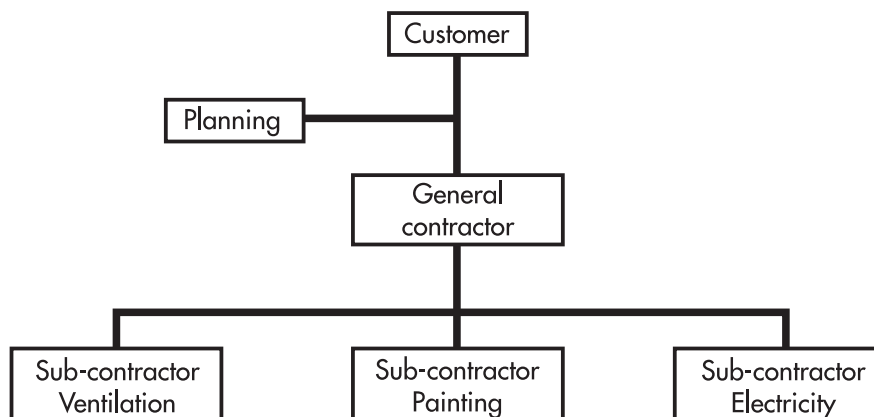


Fig. 2, general contracting

In the project form of general contract (see fig.2) the customer has made an agreement with the general contractor who is responsible for the construction of the building. The contractor can either do this himself or hire sub contractors. Either way he is responsible for the construction towards the customer. The planning responsibility lies on the customer who can either plan it by himself or hire one or more consultants.

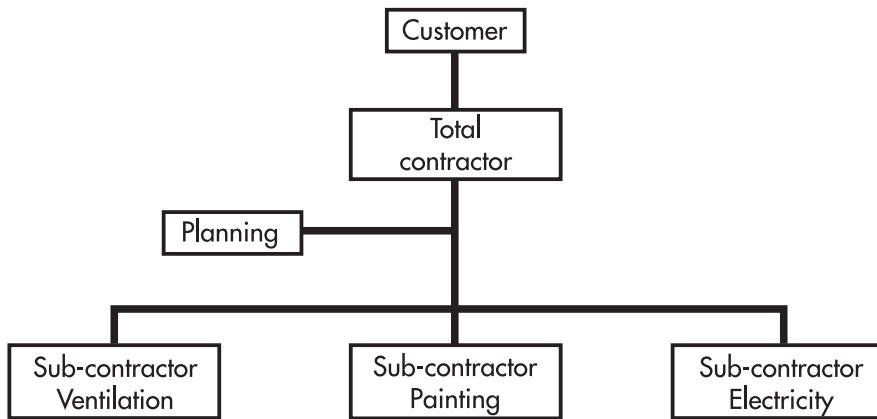


Fig. 3, total contracting

Total contract (see fig. 3) and general contract are very similar. The differences between the two are that under total contract the contractor is responsible for the planning as well. For the customer, this means there is only a need for one partner in the deal. The contractor is responsible for all aspects of the building.

Total contract is best suited for those who have no experience with the process, such as many customers. Generally total contract slightly more expensive, but on the other hand there are fewer risks involved.

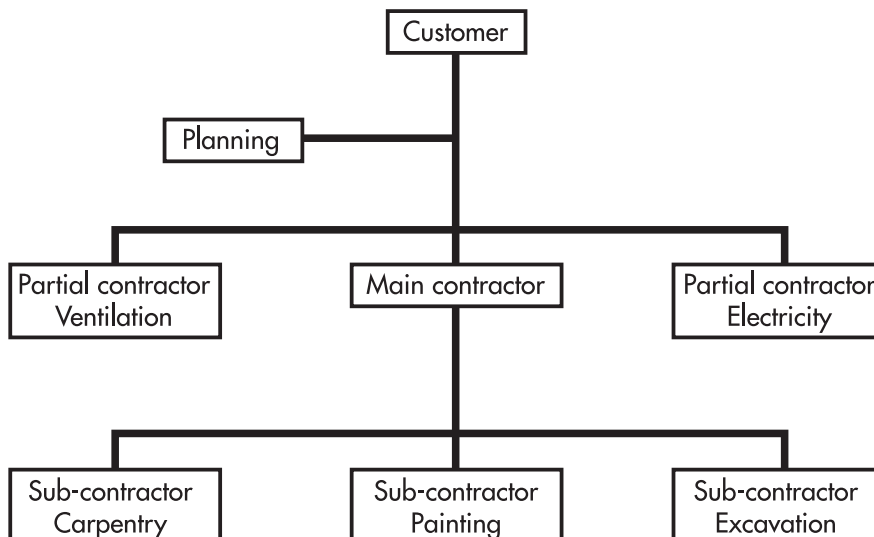


Fig. 4, partial contracting

The project form of partial contract (see fig.4) differs more from the others. Here the customer makes deals with several contractors, each responsible for his field. For instance the electrical contractor could be hired independently from the other participants.

The planning is the responsibility of the customer, who can hire any consultants he like or do the job himself. Real estate corporations who are more experienced in construction of buildings would probably choose this form or the general contract. To separate the planning part from the rest of the responsibilities and handle it themselves could let them to be more in control of the finished building.

## Participants of a project

Planning and construction of a building requires the interaction of many persons, not only in the actual building phase, but also when planning, calculating, drawing and so on. Each of these participating persons has their unique competence and responsibilities which makes them indispensable to the project.

A typical project involves several independent participants. Each participant is often a separate company but occasionally one company has several parts in a project.

Some participants are obvious, the customer for instance. The one who wants to build the building or house is of course important. Then there are the different participants who actually design and plan the house, architects, construction engineer, electrical designers, plumbing designers, ventilation designers, i.e. the people who work in the planning phase. In the production phase there are the workers who actually build the building and its parts. Here must also the building managers be mentioned, as they also participate in the process in its final phase.

### **The customer**

The one that places an order for a building or house is the customer. Customers are also users in many cases, but not every time as building managers sometimes place orders for buildings and rent them or parts of them to users. In most projects the users are involved from the beginning of the project, but not always. Sometimes a building management corporation speculates what need there is for a building and starts to plan and build the building. The users of the building are in such a case found later. The customer is the one who defines what the building is supposed to be used for, and provides special needs and requirements, which should be gathered from users.

It is also quite common for construction corporations to build residential buildings without having users or customers to each apartment from the start. This type of project is only built in areas where there is a pronounced need of apartments so it is usually not a major risk. Often it is no problem to sell the apartments before they are finished but as always there are exceptions. The last few years there have been several high profile projects where high priced apartments have proven to be almost impossible to sell, in spite of the well planned apartments and a great location.

To be able to build in a certain location the customer needs to have a right to build there. The planned activities in the building also need to match the city plan. These rights are handled by the city. There are many regulations and procedures to be followed before a building can be built.

### **The architect**

Architects are important when building a house. The architect is the link between the customer or user and the rest of the industry. It is the architect that investigates what needs the customer has, and then designs the building in a way that will meet these needs. It is common practice that the architect also has a role of coordinating the other participants during the process. This comes naturally as the architect has the most complete image of the finished building as well as a clear view of what the customer wants.

The architect's role in designing a building is also to design the building aesthetically. This is a very important part of planning a building; not only to give the building a good look but also to make sure it blends in well with the community it is built in. There are examples where architects try to make a distinct contrast between a building and its surroundings, but hopefully this will be an improvement in the aesthetics aspects instead.

The architect describes the entire building in a functional way, to a very high level of detail. However, the architect does not design any technical details. Most things are described in a general manner, leaving the decision about the exact technical solution to someone else. Depending on what kind of detail it is, the proper person takes the decision on the matter.

Architects produce drawings of the entire building, plans that are called A-plans. Every aspect of the building is covered in a functional way. These drawings are very detailed, even positions of individual tiles in a bathroom may be specified, positions of light switches, what each room are to be used for, how many people the ventilation system must be dimensioned for and so on. All this information has traditionally been drawn on paper, and then sent to other the participants.

As a complement to the drawings, descriptions are also written. These descriptions are exact and cover almost every possible aspect of the building. They contain information like materials, colours, what handles are to be used on the doors and so on. Descriptions exist for all rooms in the building as well as the exterior.

In later years, the work has more and more become computer-based. Many architects are today using CAD systems to create their drawings, the information can then be sent electronically to the other participants for instance via e-mail. This saves money, but on the construction sites large paper drawings are still dominating. PC (MS Windows) is the dominant computer system that is used and the most common application is Autodesk's AutoCAD.

Sometimes the interior of a building is designed by an interior designer. In this thesis the interior designer will be seen as the same participant as the architect. The interior designer designs the interior of a building. Details such as floor material, colours of walls, what lights are to be put in and sometimes what furniture are to place in what room, are decided by the interior designer. How detailed their work is varies from project to project.

Architects usually are hired as consultants for one project at a time. Some customers who build many buildings have non-formal agreements with architects that they like working with. Much of the process of building a building is about cooperation between participants, and often a group of participants that can cooperate well are hired again.

### **The engineers**

The technical details of the building are designed by several different specialists. Each specialist

has his or her area of expertise and designs every aspect of the building within this field. These specialists are here referred to as engineers. Often they are referred to as consultants since they are almost always hired as consultants but other participants in the process might actually be working as consultants too which makes the term somewhat misleading.

In some projects there are special demands from the customer that implicate how the engineers solve their part of the project, but usually they are free to choose their own solutions, within the architect's plans naturally. Most engineers specialise in one field but some companies cover several of these areas.

The larger areas, which also can be broken down in smaller fields are construction, electricity, ventilation and plumbing. There are more fields than these. The most common way to involve these participants in a project is as consultants. Most engineers today work according to regulations like AB 92 ("Allmänna bestämmelser"/general regulations translated) ABK 94 ("Totalentreprenad"/total contract) ABK 96 ("Anlitande av konsulter"/hiring of consultants).

The engineers have very different tasks and responsibilities. Constructors make calculations on structure strength, electrical designer designs the electrical system, and others design the plumbing and ventilation. The work of an electrical designer varies a lot from the work of ventilation designer and is usually hard to see as the same participant. However, when seen in the perspective of information flow, their parts in the process are very similar.

Many of these consultants have to work together and coordinate their work at some parts of the project. If the ventilation designer decides to put a large fan on a specific place in the building, the electrical designer must make sure that the electrical system supports that. Most of these matters are solved without much need of communication. The architect usually has assigned a certain space for use for the fans and such objects and the electrical designer must then only dimension the electrical system according to the specific equipment chosen by the ventilation designer.

All of these engineers base their drawings on the A-plans. Each of the engineers delivers detailed drawings that cover everything within their field of expertise as well as descriptions of the chosen solutions. The description includes information on everything needed to build the system, such as materials or manufacturers and models, when applicable. The people who build the building then use these drawings and descriptions. All the engineers ever deliver is information of some kind. They do not buy or sell equipment, they only choose what type of equipment is to be purchased and how it is to be installed.

Each engineer has his own specialised computer system to aid in the work. Most users work in a PC (MS Windows) environment, since the architects makes their drawings on PC based systems and the files are sent electronically. The software tools for the engineers differ between the different engineers, but Autodesk's AutoCAD is very common.

### **The construction workers**

The construction workers are the people who actually build the building. This step is a complex process itself and will be presented very briefly in this thesis. Construction workers will here include all the various people who work on the construction site. They are not in real life to be seen as one group, they include everything from concrete moulders to carpenters, electricians and painters.



The construction workers also work as separate companies often referred to as the entrepreneurs. Each entrepreneur is responsible for a certain part, such as installing the ventilation system, or making the electrical installations. For each of the different types of engineers there are entrepreneurs who follow the plans made by the engineers. Therefore the word “construction worker” may be somewhat misleading here since it includes many different types of people. This is because all construction workers are seen as users of information in the thesis. They never produce information and are therefore unimportant when discussing production of information. They are not unimportant from the aspect of the information flow since they are the users of this information, and it is their needs on the information that has to be met.

Traditionally, construction workers are using paper-based drawings, and to a large extent, they still use them today. There have been attempts to have computer-based systems on site, to simplify updates and changes of the plans, but these have usually failed due to different reasons. Many agree on that it would be good to be able to use electronic drawings on site, since these are much easier to be remotely updated. The big save in money lies not in not having to plot the plans on large papers, but to eliminate the risk of not updating all of the plans, but only some of them. This does from time to time lead to errors in the finished building.

### **The manufacturers of building material**

The material manufacturers are the companies that provide the building materials. This could be anything from doors to steel beams or concrete precast; all are equally diverse as the construction workers.

Some would argue that the material manufacturers do not participate in the construction process. It is true that they do not directly affect the outcome of the building, but they do provide something important; the building blocks. The architect is limited to choose doors, windows that can be purchased and therefore the manufacturers have an influence on the building. The manufacturers do of course provide the elements that the architects ask for but standardised products are the most common; custom solutions cost significantly more.

The manufacturers provide some drawings material for architects to refer to. This material is descriptions and drawings of the building element and occasionally there are also pictures. These are included in the buildings plans as a reference.

### **The building managers**

Building managers are the people who are responsible for the building, once finished. Sometimes it is the people working or living there themselves, and sometimes these people rent the building or a part of it from the building managers. The owners of the building could let someone else handle the managing of a building for them.

Once the building is finished, the participants of the project inspect it. This means that the architect, electrical designer and the other participants walk around in the building and inspect it. Whenever an error is found, the company responsible for that part has to either replace the erroneous parts or compensate it economically. This could be virtually anything. If the architect has decided that a certain sort of door is to be used in a building and the person responsible for purchasing doors got a better price on some other sort of doors, and therefore bought that one, it could be considered an error. These situations are not uncommon today. Once the building has been inspected it will be delivered to the building manager, which often is the customer.

The building manager will also need a so-called reference-model of the building. This is a plan of the building, describing it very high detail, much like the plans the building was built after. This is needed when changes are to be made to the building. The original plans cannot be used for this purpose since it is common that buildings are not built exactly according to plan. Sometimes it is because of errors in the plans and sometimes the plans where for some reason not followed. The making of the reference model is always a separated project. It could be ordered with the drawing and construction of the building but is considered as a separate project. Often the architect is given the responsibility to create these plans. It is the most natural choice since the architect has great knowledge in the building. Often the reference plans are based upon the original plans, to some extent.

Building managers are responsible for repairs and renovations. It is therefore important that they have updated plans of the building at all times. Every change to the building should be documented into the reference model. The reference plans are sent to the persons that make the repairs and alteration on the building and so it can be used for planning the changes

Architects also must store plans in an archive. Typically architects store more information regarding the technical specifications of the building, and less information on the use of the building. The owner of a building is supposed to be able to go back to the original architect and find the original plans from which a building was built. The architect must not update these plans as the building manger is altering the building. Architects must however archive all alterations of buildings they themselves draw or plan.

## Cooperation in a project

There are many people involved in a project. In most projects project meetings handle cooperation and communication, where the project leader coordinates the participants' efforts. The people involved in the particular phase of the project attend these meetings. In larger projects, meetings that only include people from one discipline are common. For instance a meeting with only the people that work with electricity and the project management are represented.

In smaller projects, such as planning a small residential building, everything is handled less formal. Still the formal aspects such as contracts are important and followed. Standardised contracts that cover almost every aspect of the legal issues exist and are most often used.

The need for cooperation is large, but unfortunately cooperation seems to be working poorly. The process of building houses is often referred to as a relay race with poor baton handling [Nyman '02].

## Problems for the industry

Today there are a few problems for the industry. The problems have been perceived as problems for quite some time without any successful attempts to solve them. The bigger issues are briefly described here. Problems like an economic recession are not considered.

### Limited perspectives

In the process there are many different companies involved who only have economic interest in their part of the process, not in the complete process. An entrepreneur that is hired only to do a small detail doesn't really care for, nor have any economic incentive for the rest the process.

Each company has therefore optimised their part of the process, independently from the other parts. Each participant makes its own plans to the level of detail that its part demands, and not enough to fully support the one after them in the process. This has led to a less efficient process, when seen as complete process. It is in fact a local and not a global optimisation.

Problems like these occur less frequently under total contract, since the participant who has the total contract has a stronger incentive to make the process efficient. He can spend resources in the early stages of the process in order to make savings later in it. Total contract are not always better since the contractor might hire sub contractors and run the project without addressing the efficiency problems. Total contract however gives an opportunity to make it more efficient.

This problem usually not perceived as a problem by the participants. They are in no way affected by it. The problems come at a larger scale, when the entire process takes more time and therefore cost more. It is the customer or building manager who is affected by it since the building will cost more to construct. For the total contractor a more efficient process could mean higher revenues. The consultants are often charging by the hour. Giving them better support when it comes to information should mean that they could finish their part faster and therefore should charge less for the job.

#### **Incompatible software systems**

Much of the information handling in the process is computer based. Architects make CAD drawings of the building, and these then have to be imported by the construction engineer. At every import of information there is always a risk of information to be lost or altered. Licence costs are a large expense for both architects and engineers.

The solution to this problem has been to use a de facto standard, such as Autodesk's AutoCAD software system. This is limiting to participants who would like to use other software. Today 57 percent of the time spent by architects making drawings is spent using AutoCAD (and another 3 percent uses AutoCAD ADT, architectural desktop). The same figure for the engineers is 76 percent. [Samuelson '01A].

This problem also stems from the fact that the different participants have different needs. The tools developed for architects are not always suited for engineers. Traditionally architects have gotten computer support some time before the engineers, and this has been perceived as an incompatibility issue among engineers.

#### **Incompatible data formats**

This problem sounds, at first glance, as the same problem as the previous one; technically it is. It is another problem that comes from incompatible formats and systems; this one appears when these formats are archived. It usually takes several years before a building is to be rebuilt, and with the short length of the product cycle of computer systems today, it might be hard to find a system that can read old formats. Look back ten or twenty years in time and look at the formats that were used then. How many of these formats can be opened by today's systems?

Likewise it is hard today to know in what format data should be archived in. Since data usually cannot perfectly be converted between formats, most people choose to archive the data in their original format. Building managers can today have archives of reference models that are in many various formats, and will therefore need software systems for each of the formats. Other chooses to let their archives remain paper based.

### **Double work**

Today it is often perceived as some work is performed with a double redundancy. Work that someone else has done previously has to be remade by someone else. This comes because of poor information sharing; information is often not shared unless specified in a contract.

The whole problem of not sharing information originates in several things. First, there is often no practical way of doing so. Software compatibility issues, difficulties of knowing what other would want in the project, no tradition of sharing information other than the finished product to name the most important.

Another reason is economic. In case something goes wrong, no one wants to risk being responsible for something he did not have to be responsible for. Errors or mistakes are corrected by either letting the party that made the error correct it or with an economical compensation. This depend on the kind of error. If it can't be corrected or the error is acceptable to live with, economic compensation is preferred. Either way error cost money for the one who is responsible; even though it was not in the original contract. This risk combined with the fact that no economic profit comes with sharing the information at all leads to information being kept for as long as possible.

### **Collision in plans**

In some projects there have been problems with plans and drawings that are incorrect. Most often the problems have been such as ventilation pipes and electrical cables taking up the same physical space. The engineers that make the drawings have simply made mistakes that haven't been discovered until someone on site has to actually install the components. Today most plans are 2D and it is hard to make sure that there are no collisions. These problems haven't been very common but when they occur they delay time schedules, plans has to be revised in a hurry and depending on the situation, components that already have been installed has to be removed and reinstalled. It is a disturbance for the entrepreneurs who make the installations when the plans are incorrect. It also introduces scepticism towards the rest of the plans.

### **Experiences from earlier projects**

Experiences from previous projects are usually not taken into consideration in the next project. This comes from the short term partnerships that are common in this industry. There are many small firms who work together for a short period of time. One small corporation does not learn from the mistakes of another. Different companies also work in slightly different manors and these differences can sometimes cause problems. Often experiences from a project can affect which consultants and entrepreneurs are hired in the next project. Groups of firms that work fine together then form informal alliances and keep working together. This is not good from a competitive aspect since new companies cannot compete at equal conditions.

### **Novice customers**

Since many customers are not used to build houses, problems sometimes arise because of this. It is tempting to use general contract instead of total contract due to the potential economic savings. Poor project management could seriously disturb the project.

The customer is the only one in a project, who knows what is right. It is in fact the definition of the customer's part in the project. A customer who cannot be clear, and communicate the needs and expectations can lead to a building that is poorly adapted to the users needs.

### **Poor calculations on material usage**

One part of the process is deciding how much material is to be purchased. Today this is not done very exact, but often only an estimate. There is always a margin added to the estimated value as well, not only to compensate for an inadequate estimation but also since some material normally gets damaged or unusable. When it comes to concrete it has been estimated that as much as 30 percent extra sometimes is purchased and then wasted.

Not only the amounts of material has to be ordered. In some cases there is not enough space on the construction site to store all the material. Material is then ordered in a way that it is delivered at the same pace as it is being used. Problems with delays therefore cost even more and the time schedules are even more important to keep.

### **Poorly updated reference models**

Building managers are required to keep updated reference models of their buildings, but in reality this is not always the case. It is not unusual that reference models are incorrect, especially for older buildings. These variations cost money when buildings are to be rebuilt. At some projects that aim to rebuild a building or part of it, someone must go to the location and then create new plans of the existing location. These plans will only serve as background information when the architect makes the new plans.

These errors in the reference models, produces extra costs once a building is to be altered. It is also a cost to update the plans, so it is in fact not always done as it is supposed to.

### **Poorly adapted software systems**

Many of today's software systems for CAD have been developed for other industries than then construction industry. This is itself not a problem, but the software systems used could be better adapted to the need of this industry leaving a big space for improvement in user interfaces. It is seen as the poor adaptation level hinders the spreading of this technology.

## **Summary**

There are some problems for the industry, and there are several reasons for this. Much of the industry's computer tools have slowly been integrated into the work process. Today's process is in fact not adapted for the computer tools available and vice versa. The process is better suited for hand-drawn plans and the computer-drawn plans are fitted into this model more or less by force; the full potential of computers is far from fully utilised.

Other problems with today's process come from the fact that few participants care for the outcome of finished product; each participant is only concerned with his part of the process. The business models used today more or less forces firms to do this. Small margins and small or no incentive to aid other participants leads to a more egocentric work environment.

## **IT in the building process**

Naturally an industry as large and important to society, as the construction industry is, is subject to research, research that aims to evaluate its past and to improve the industry's methods. The funding for this research and development comes both from the industry itself but also the government. Between 1998 and 2002 much of the industry's research was carried out under

the project “IT Bygg och Fastighet 2002” (here referred to as ITBoF). It started in 1998 and had its final evaluation in the late 2002 [Johannesson et al. '03]. The project was funded by both government and industry organisations. The total budget over the five years was 113 million SEK.

### **Goal and means of ITBoF**

This project is large and aims to change the foundation of the industry by developing new work-methods, providing new tools and an improved work process. Computers have previously also been a natural part of the work in the industry, but ITBoF tries to integrate the computers more closely than ever before. These plans are not new; the idea of the integrated CAD is as old as CAD itself. However, not until now have the computer industry come far enough to support this “vision” in a commercially realisable way.

The goal of the project was essentially to

- Increase customer benefits
- Increase process efficiency
- Increase competence within the industry

This was to be done by:

- Giving organisations and corporations the possibility and knowledge to share information across public communication networks.
- Changing the actual information flow so it will be based on digital communication.
- Making all types of information from ongoing projects and information regarding existing real estate to be available in digital form.
- Public sources of information such as laws, regulations, norms, product information and geographical information to be available in digital form.
- Students of both high school and college level shall be given an IT education that is well adapted to real estate and construction.
- Those already working within the industry shall be educated in IT where it is relevant for their role.

This can be summarised as an attempt to change the information flow in the building process. Information is to flow from the start of the project to the end, not getting caught in the early stages of it, and then having to be reproduced again. The need of conversions or retyping of information, as well as the potentials of misunderstandings and errors due to poor information sharing are to be eliminated or at least significantly decreased. Many of the problems for the industry can be traced to problems of information handling and the projects aims to propose solutions them and test these solutions.

### **Project results**

The projects own evaluation of the project showed that the project had met its goals to high extent. New knowledge, new tools and the outline of a new way of using information technology within this industry have been developed. Some say that the project has a deep support in the industry as well as for the IFC standard; others however, criticise the project for not reaching out with its results to the people working in the industry. The evaluations stated that the program was unique as an industrial development project, since the program tried to create a national strategy, for a whole industry, for a common IT infrastructure. The evaluation also showed that work was done in a scientifically correct manor. There where comments but the overall quality was high, both the results and their presentation.

### **Sub projects**

The program included several sub projects in a few areas of interest. These were: communication and knowledge distribution, interfaces, product and process models, classification and standards, implementing modified work patterns. These projects all aim to solve the problems for the industry by creating the common IT infrastructure.

Each of the projects under ITBOF has a project number. The project name and this number will be used as reference to the projects in the text. The project IFCim, which developed a system for climate and energy simulation will for instance be referred to as (ITBOF: IFCim 98310). Information regarding the projects can be found on CD-ROMS distributed with magazines and other places or at the website [www.itbof.com](http://www.itbof.com).

### **IFC**

IFC stands for Industry Foundation Classes and is an initiative taken by the IAI (International Alliance for Interoperability) in the early years of the nineteen nineties. The main idea behind the IFC is to create a common software infrastructure for architects, engineers, constructionists and building managers. An infrastructure for storing, communicating all common information for a building, that is independent from hardware or software platforms, and can be used by all participants at all stages in the building process.

A part of ITBOF involved IFC. The IFC part of this project worked with adapting IFC to Swedish classifications as well as testing the use of IFC in pilot projects. IFC is today compatible with the classification system BSAB (current version, BSAB96, is based on ISO12006-2).

### **A product model**

IFC is a product model. A product model is according to ITBOF [Tarandi '02] defined by ISO (ISO/TC184/SC4 1993A) as description of a product, an organisation or virtually any other part of the planet. The information within the model should be integrated, or the objects that the information consists of, should have relations allowing information to be searched in a structured way. Each object is a part of a specific building, is placed on a certain floor, belongs to a specific class of objects and all objects are connected to each other. The definition also states that the model should give a possibility to handle the product through its entire life cycle.

The concept of a product model can be adapted to any type of product; cars, aeroplanes, parts of an aeroplane, buildings such as in this case, or virtually any family of products. The product model contains more information than traditional drawings of the product. An exact CAD representation is not alone a product model unless it is supplemented with semantics or meaning that describes the parts and their relations.

Since the product model should be able to support the building through its entire life-cycle this means it will support the managing phase as well. The model can be used to administrate contracts between managers and tenants, parking rights and so on. The model can be used for this, but this requires that someone models and builds these parts for the system. The product model is only a description of the product; it is not a finished software system that can be bought of the shelf.

### **3D models instead of lines**

The product model that IFC describes is being realised by creating a standard for modelling buildings and building elements. An IFC model is a 3D model of the building, with information regarding the elements attached or linked to it. Information concerning each building element is stored with the element, accessible from within the model.

Building elements also have relations to each other. Electrical outlets are attached to a specific location on a specific wall. That wall is standing on a foundation that rests on something else and so on. The entire building is modelled with this information. It is far more than a geometric description of the walls, floors, ceilings and roof.

Information about a special detail can be linked to the representation of that specific instance, or class of objects. This piece of information can be data for the element, pictures, texts, invoices or any other type of information. The information can be accessed through the model, allowing a fairly intuitive interface to a large amount of information.

The geometric descriptions of objects within the data model can be read and displayed by the other applications, but far from always altered. Details are described by someone who designs in one application and the person observing the detail can be using another application that lacks the possibility of altering the geometry of the object. It is possible that there will be no application that has the capability of changing all aspects of the IFC model.

Many geometric objects cannot be altered in any application, since they represent a specific object. For instance, it is impossible to scale objects like a ventilation fan; this geometric object represents a real object that cannot be scaled. If a larger or smaller fan is desired, the proper engineer can select another model instead.

By keeping data and properties for each element gives the possibility to let computers analyse the building. Accessing list of material usage is very simple. The making of cost evaluations for interior details is simplified when exact number of each detail easily can be found and calculations can be automated.

IFC also holds a time perspective. It is possible to include the construction order for building elements. All elements can be given a specific time when it is to be installed on site. These time schedules can be altered and alternations can be kept in the model as well. This is commonly referred to as 4D planning and supports handling of delays and other re-planning. In some projects this is a very important aspect the process. Due to lack of on-site storing space material must sometimes be delivered to the construction site at the same rate it is being used.

Having all this information stored in the same database also provides a way to search the data for details. Searchable systems have great potential to speed up work, and make large amounts of data comprehensible.

### **Online document handling**

Since data can be linked from within the model, the model also provides a powerful interface for a document handling system as well. This is very important for building managers, who want to save data from the construction phase of a building as well as new information produced during the life-cycle of the building.



The information stored regarding a specific building is information regarding leasing contracts, fire inspections, ventilation inspections, invoices, orders, reports of errors, user evaluations and so on. Most information is in some form of formatted text or pictures. Much of this information has no clear connection to a specific building element or part of the building. But for those documents that has a connection, a link within the model is perceived as highly valuable. There is much work done surrounding document handling today. It is run as separate projects under ITBOF but it not at all a part of IFC.

When all participants are working with updated information changes immediately are visible to other users. There is also no need to transfer information or coordinating work between offices. Using product models also provides documentation of projects in a standardised way, which simplifies reusing information, both within a project and when looking at other projects. The models themselves contain all information from their respective project.

### **Workflow based on IFC**

The model will normally be created by the architects, who model the building using an IFC-compatible 3D CAD tool. Everything from where walls and stairs are located to how the tiles in the bathroom are to be placed. The scope for the architect has not changed so for each window or door it is specified what kind of door or window, what kind of lock and what kind of mounting and so on.

Much of the architects work has previously been done by creating examples. If there are ten identical bathrooms in a building, the architect will only draw one of them, and making a note that the other will look the same. When working with 3D models the architects will have to specify each bathroom. The software application aiding the architect will most likely provide the function copying or linking objects, but the work will nevertheless have to be made.

Once the architects are done, the engineers can then start to add their information such as electrical wiring, ventilation, plumbing and so on. The architects and the engineers will most likely work simultaneously on the building, but the architect must start by outlining the building. The engineers need walls, floors and rooms in order to do their work. The engineers will, just as the architect, specify their building elements, for example the electrician must specify what kind of wire is to be used for each purpose. All this information is added to the database the architects worked on. All through the process information is added.

The descriptions that are written today must still be written. Some parts of them already exist within the model, extractable from the 3D-geometry, while other pieces of information must be manually added. When the architect and the engineers are finished, the database should be filled with all the information necessary to build the actual building. From the file it is now possible to extract how much building material is needed to build the building which is very valuable. With these 3D models more accurate figures can easily be calculated, automatically. The model used for this calculation will be improved over time, when more finished buildings to evaluate will be available.

Instead of using the paper drawings drawn by the architects, the construction workers have access to an exact model of the building. There is no need to measure anything manually on papers, which is incorrectly being done today in some projects. Measurement can be extracted from the model, which easily can be zoomed, rotated, panned and so on. Or, if the construction workers want to, traditional paper drawings can be extracted from the model. These drawings

would be without measurement errors, or inconsistencies. Measurements can automatically be added and therefore save a lot of time.

### **Reference models**

The reference model is supposed to be updated each time the building is rebuilt, or changed in any way. The people who actually make the changes to the buildings use the same software tools as those who construct buildings. They have to use the reference model, when making changes, so it is very natural for building managers to also use IFC-based plans of their buildings. The building manager is responsible for updating the changes once made.

Looking up details in the reference model is something building managers do on almost a daily basis. In an IFC model all information regarding specific building elements are accessible, so it is therefore easy to look up classifications if a building element is to be replaced. If a new door is to be replaced, the new door has to have the correct fire classification, lock and so on. All this information can be found in the model, when it has been properly updated.

When changes are to be made to a building, for instance changes to the electrical system, the electrician can be given access to the building's reference model. All the information needed are there, and when done, either he himself or someone else must update the reference model with the changes.

The 3D model replaces the traditional paper based plans of the building. What originally was a large amount of large drawings and binders with information is now a digitised, searchable, easy accessed archive, which can be copied if needed. Remote access is also possible with a digital format, which is valuable for building managers that have interests in a larger geographical area. Today many building managers have small archives at each regional office. Digital formats allow centralisation of these archives.

### **The importance of IFC**

But what is IFC? Each of the groups of people involved in the process has their own, highly specialised applications. All these applications have to be able to communicate with each other, and this is where IFC is needed. IFC is the infrastructure for communicating between the applications and is a definition on how elements are to be described; it is sort of file format. Not just rules on how to serialise data; it also includes semantics, or meaning that explains what the parts are and how they are related to each other.

IFC is a product model, built around building elements. A door manufacturer can create a building element that represents a door. The look of it, as well as classifications, can be made into on building element that can be used by the architect or an engineer to represent the door in the model. All information belonging to that door can then be located from the door. Most of the building elements can be found in a product database from which the user selects parts.

All applications do not support all functions of IFC. Each application only supports its users in a specific area. An application aimed at plumbing, has no need for supporting functions concerning electrical wiring and leaves that to another application.

The idea of ifc is however that all information is to be visible. Some engineers have previously been known to make drawings of elements that collide. In the plans the same space has been used for both ventilation pipes and cables at the same time, which, naturally, is impossible to actually build. When using 3D CAD the second engineer clearly sees what space the first engi-

neer has already used and therefore never produces the problem. The software systems will also warn if such a collision would happen.

It is important to point out that IFC is not a product suite. There are several competitive products from different software companies available today. More products are on the way and they are all competing. The IAI only provides the common language of these applications; the applications can then communicate with each other. Different products support different parts of IFC, and provide different functions for their users.

### **Implementing IFC**

The IAI only provides the file format, no source code or examples on how to implement the standard. There is extensive documentation to support developers available. The format itself is based upon the format Express which is also used by step (STandard for the Exchange of Product data). Step is a similar project originally initiated by car manufacturers and is today an ISO standard that covers many various areas. There are software developers that provide toolkits for implementing IFC, but these are not supported by the IAI. These toolkits have become more or less de facto standard among smaller software companies.

### **Compatibility**

All applications that are compatible with IFC are compatible with each other. All the applications that can read and write files that are compatible with the IFC standard, and therefore are able to communicate with each other. ITBOF has reported that with existing software that use IFC this compatibility works fine. There were few problems with loading data created by another software application.

To say that the software systems are compatible does not mean they can replace each other. Some systems support some work tasks and other support other. To say they are compatible here means that they can read the other applications output data and present it in a correct way. If one system opens an IFC file and alters it, it will not alter or in any other way corrupt data it cannot understand. Data are handled as object with properties and properties that are not recognised will be left unaltered.

### **Versions of IFC**

The work of defining IFC is in itself a process that so far has taken many years. It is not yet finished but at least usable at its current status. The current version number of IFC is version 2.0, but many software systems that support IFC today use the previous version, 1.5.1. These different versions are compatible in at least in one direction, i.e. applications that can open files of version 2.0 also can open files of version 1.5.1.

The work surrounding the definition of IFC will probably be continued for many years to come. New versions will introduce new functions and features yet hopefully still remain backwards compatible; this is very important if architects and building managers are going to use IFC for archiving.

### **Other applications of IFC**

The use of IFC gives access to many more functions which were not possible without recreating the plans or drawings in another software system. For instance VR (Virtual Reality) applications,

various simulations and more have been created to support the use of IFC. These functions have been previously available, but at a higher cost. With IFC it is much easier to find software for conversion to a VR format. It is naturally possible to build a VR environment capable of reading IFC directly as well.

The project “VirtuellCAD” [Berg ‘99] is a project partially funded through ITBOF (ITBOF: VRCAD 98326) aiming to link a CAD application (ArchiCAD) to a VR system (Sense 8). The idea is to not only to visualise the CAD data but also to give a possibility to alter the model from within the VR world. This project uses specialised API’s (Application Programming Interface) to realise the functions but there are no fundamental obstacles to use IFC as the communication instead.

In the ITBOF project (ITBOF: IFCim 98310) a new tool capable of performing climate simulations, has been developed and tested. This project has led to a commercial product called “IDA Klimat och Energi 3.0.” There are also other tools that are capable of making calculations on the models; which use the models for dimensioning parts and components. For instance CADVent (ITBOF: CADVent 00751 (part)) is a ventilation planning and modelling tool that can calculate parameters like the fall of pressure and noise in ventilation systems. It is implemented as a plug-in to AutoCAD. This system can aid the engineer who models the building with dimensioning and choice of components.

There have also been projects that aim to integrate CAD and GIS (Geographical Information System) to provide aid for building managers who have interests in large geographic areas (ITBOF: PM-GIS 99415).

Some systems aim to simulate sunlight in order to simulate how buildings shadow each other. For some type of areas this is important.

For building managers who have old paper or line based drawings and would like to convert these into IFC based models, there exists, at least a prototype for, such tool (ITBOF: CADPRO 98109). The application automatically converts paper based drawings to IFC models [Noack ‘01].

It is important to point out that none of these applications have been made possible by IFC, but they have been made commercially possible to use. Similar systems have been developed before, but these tools required manual conversion of the 2D CAD drawings into 3D models; a step that is expensive and time consuming.

## Theory – User orientation and IT

Most people involved in the alteration in the construction process have their background in the construction industry. To change a process in its foundation requires knowledge of the process, the participants, the needs of the participants and external factors, such as laws and regulations. However there are also other people that can aid in the changes; for instance people whom study computer tools and changes in work processes due them.

This is exactly what the research field of CSCW looks at. The construction industry is not the first industry changed due to new possibilities of computerisation. Computer Supported Cooperative Work is the most common way to read the acronym CSCW. There however are more interpretations. Computer Supported Collaborative Work is another and some even call it Competitive Work. Within this field cooperative usage of computers is studied. Often the studies look at the higher social functions in work processes as well as organisational theory.

### CSCW

There are many definitions of CSCW and one states that:

CSCW NEEDS TO ADDRESS THE FOLLOWING SPECIFIC REQUIREMENTS OF COOPERATIVE WORK:

- ARTICULATING COOPERATIVE WORK.
- SHARING AN INFORMATION SPACE.
- ADAPTING THE TECHNOLOGY TO THE ORGANISATION, AND VICE VERSA.

[Bannon Schmidt '88]

another one is:

COMPUTER-BASED SYSTEMS THAT SUPPORT GROUPS OF PEOPLE ENGAGED IN A COMMON TASK  
(OR GOAL) AND THAT PROVIDE AN INTERFACE TO A SHARED ENVIRONMENT

[Ellis et al. '91]

MORE THAN A WAY OF CODING OR BUILDING APPLICATIONS, GROUPWARE IS A WAY TO  
DEFINE, STRUCTURE, AND LINK APPLICATIONS, DATA AND THE PEOPLE WHO USE THEM

[Dyson '92]

These three definitions agree to a large extent. All of them capture a large part of what CSCW is about. But not all? Well there is always something more. Winograd defines it like this:

A STATE OF MIND

[Baecker '93]

This is a rather vague definition of a research field, but it actually has some truth to it. Much of the applied usability work can be performed while doing other things.

### HCI – Origin of CSCW

CSCW is a fairly new research field. It originates in HCI, which is a just only slightly older research field. HCI is an acronym for Human Computer Interaction. The field is also related to as CHI, Computer and Human Interaction. This acronym has the advantage of being pronounceable but besides from that both terms are the same. This thesis refers to the area as HCI.

In the early nineteen eighties, HCI really took off and in the mid eighties CSCW became an established field. During the late eighties and early nineties many of the CSCW “classic” reports and papers were written. HCI focuses on how to make computer based systems easier to use, and more effective for the user. The field is interdisciplinary and uses not only traditional computer science, but also psychology and behavioural sciences as well as graphic design.

CSCW is usually seen as a sub field of HCI, but it can be seen the other way around as well. Some say CSCW is an extension of HCI, and that the latter therefore is a subset of CSCW. One vital difference between the two is that HCI focuses on human computer interaction – hence the name, while CSCW focuses on Human-Human interaction, with a computer based system as the tool or communication channel. Since the computer is the interface between the users, both in time and or space, HCI is very relevant to CSCW. It is hard to talk about CSCW matters without talking about HCI.

HCI usually deals with matters regarding, how to give input and how to organise system output. It operates at a much lower level than CSCW, which looks at work processes and how applications are used rather than making each user interface more efficient.

## HCI

HCI focuses on the user, which is the key to building a usable system. When designing a system, the user interface should be adapted to the intended users. Sometimes this adaptation can be problematic as no single user is representational for all possible users. There are several approaches to this, creating a smallest common divider approach, or perhaps several different user interfaces.

It is also hard for designers to build a user interface that can be used by both experts and novices. This can be accomplished, but is difficult, as it often is perceived that the expert’s needs conflicts with the novice’s.

## Historic view of HCI

The problems that HCI is trying to solve are old. When computers were new there were many things to learn before you could operate the machine successfully. Today, when computers have a graphical user interface, it appears as they are easy to use. Even though the tools for building user interfaces have come a long way, there are still a lot of developers that poorly utilise these tools. How did it come to this?

In the early days of computers, only people with expertise knowledge in computers used the systems. Sometimes they built their own systems, and there were no need for specific user interfaces. User interfaces also took valuable system resources, much needed for other tasks.

The problems still exists today as the problems with poor user interfaces were not identified in time. It became apparent when non-expert users began using computer based systems on a larger scale. In the nineteen eighties, when automation of offices began to pick up pace, there where a lot of problems with user interfaces. The people who where supposed to use the systems simply had a completely different view of a computer than the people who constructed the systems [Nielsen ‘93].

Since then user interfaces have slowly changed in to the graphical interfaces we have today. The desktop metaphor originally developed by Xerox has then been adapted by Apple, Microsoft, and others, and it is today a standard approach for operating systems.

Even today many applications are built by software engineers who have no special training in HCI, or behavioural sciences. The end users must then learn the system, and adapt the programmer's view of the system to fully understand it. This works fine in some cases but it can be very problematic, and sometimes even impossible.

## Methods of HCI

As mentioned earlier many of the definitions of HCI are rather fuzzy and inexact. Some talk of definitions like *"it's a lifestyle"* (or *"it's a state of mind"* as Winograd's definition of CSCW states). This seems unscientific, but it has some portion of truth in it at least. Once you've learned it, it is more of a perspective from which you look at other problems. When designing a dialog window for an application, there are many good guidelines to remember. By following them, the dialog could be much better in the end. Someone who is experienced within the HCI field will probably have a better chance at making that dialog understandable, without any extra effort or any extra work.

Today many explicit methods for building a good, intuitive user interface exist. Iterative design, cooperative design, ethnographical studies, participatory design, various sets of guidelines are the most common ones. The point with all of these methods is to observe the user and try to understand what it is that user need, and know.

Why can't you just ask them instead? Well, asking the users politely seems like a good idea, but often the users do not know themselves what they need or what is good for them. Some of the methods mentioned involve asking the users what they need, but it is more to HCI than just implementing the user's wish list.

The methods include both laboratory experiments as well as ex post facto and field studies. The methods are more deeply described by both Nielsen [Nielsen '93] and Schneiderman [Schneiderman '98].

### **Parallel design**

A good way of saving time is to work in parallel. Traditionally software development only produces working executables late in a project, leaving little time to perform user testing. It's better to early in the project build prototypes of the user interface, testing it with real users so there are time left to alter the interface before it is finished. Changing a finished user interface takes more time, than changing it while it is being built. By testing the prototypes many problems can be found, problems that probably would have been found anyway, only this way they would be discovered much sooner.

Starting a project by building several rough drafts of the user interface is a good idea. By letting different persons build their own proposal many new design ideas can be found. The different proposals can then be discussed and the best part of each interface can be integrated into a finished interface. Letting people work independently provides a wider spectrum of designs and more ideas to evaluate. When designers work together it is easy to be influenced by others.

### **Prototyping**

When performing user tests it is important to have prototypes of some kind. The prototype does

not have to be working, sometimes paper mock-ups are enough; they only have to communicate how the finished interface is supposed to work. By sending over a document containing the specifications to the users and ask for opinions will probably not give any good results at all. Users usually cannot understand these documents as well as a developer can.

Prototypes can then be discussed with users, both to let the developer learn more about the users, and so that the users can imagine using the systems and start evaluating the interface. Details that feel awkward for the users can quickly be discovered and replacements can be found.

## Identifying the users

To “*know your users*” is an important part of HCI. How else can one create a good interface without knowing the actual users? Therefore a lot of effort is put into identifying users at an early stage of the development process. By making an ethnographical study of the user’s work as it is before the new system is built, much can be learnt of the users and their work. Often it is better to study the work instead, or at least as a complement, to talking with the users. Users and developers tend to perceive different parts of the system as difficult to implement. Also parts of the work might be important to developers, but can be seen as insignificant by users.

This comes from the fact that many users have poor knowledge in the development of computer systems. It is nothing strange or wrong with this, it is simply not the users’ responsibility or area of expertise. Users that do not know how computers are programmed have difficulties predicting which parts of an application are hard to build.

## Consistency

A good user interfaces should be consistent as it always is easier to learn something that is familiar. Consistency is important in every aspect of a user interface, for instance such details as in what order the Yes and No button are positioned on standard dialogs are not even noticed by users. Users are so used to these details that they fail to recognise them. Most of the components in a user interface are today standardised in a consistent way, which simplifies both construction and use of user interfaces.

But why stop there? Why not try to make the whole product consistent? Not only the user interface, but also help screens, printed manuals, tutorials or what ever information available for the end users. By being consistent in naming objects and concepts everywhere they are referred to it is easier for users to understand and learn systems.

Many large corporations try to go even further by achieving consistency between different products as well. Most parts of the user interface from Adobe’s photo editing tool Photoshop can be recognised in Adobe’s graphic design tool Illustrator as well as page layout application InDesign.

Consistency between products can be a big advantage when trying to sell products. User who have bought one product, and learned how the interface works, will have an advantage when learning one that is similar. This might tip the odds in favour of them choosing the second product from the same company.



## Benefits of HCI

There are several ways to define the benefits of HCI. For different parts of the organisation the same consequences can be perceived in very different manors. For the end user that uses a system, a good system can lead to less frustration and make the work more pleasant. A good design of a system might also produce less stress for its users. These are factors that cannot be perceived by a corporation and in the same manor the corporation gains positive effects that cannot be directly perceived by its employees.

For a corporation the benefits are that user orientation eventually saves money, in some form. There have been many calculations on how much money that can be saved, but all comes to different conclusions, which can be explained by the different aspects that can be considered. By improving the work-speed of the end users, time, and therefore money, can be saved. Some point out that a more usable product gives higher satisfaction among the staff that uses the system, and how does one value that in money? This will have effects on the economic situation for the company as well. Employees are home sick from work more seldom? Better efficiency? It is all very hard to convert into direct figures, but almost all of the estimations show that money can be saved.

The development cost is higher, but the use of HCI approach can also save a lot of money. However it does not save money for the developer, but instead saves time for the end users, and therefore money. HCI should therefore be considered as an advantage when selling the product. It is perhaps what makes the customer chose the specific product. These are the positive effects for the developer, better products and higher customer satisfaction.

Even though the use HCI methods can add much value for the finished product, it is not widely used by software corporations. Some companies have come a long way, and has fully incorporated HCI into their work process, while others haven't even heard about it. Since HCI requires extra resources, in the form of time and personnel, it therefore costs more to use.

Most customers do not know about the benefits and expects not to have to pay extra to get an application that is usable or is easy to use. This is a problem when trying to “sell” the concept. Only the initial cost is seen – not the potential savings. Traditionally software corporations did not spent any extra resources on adapting their software for the specific users that were supposed to use the product.

A corporation that sells off-the-shelf products have a lot to gain from having good user interfaces. By earning a reputation of having easy to use interfaces, sales can increase. The user interface is, after all, the only thing that the end user ever sees.

USER INTERFACES ACCOUNT FOR 48 PERCENT OF THE CODE IN MODERN SOFTWARE AND ABOUT A THIRD OF THE WEIGHT IN SOFTWARE REVIEWS. IN CONTRAST, USABILITY ENGINEERING ACTIVITIES NORMALLY TAKE UP ABOUT 6 PERCENT OF DEVELOPMENT BUDGETS; THEREFORE, BETTER USABILITY ENGINEERING METHODS HAVE HIGH LEVERAGE ON PRODUCT QUALITY.

[Nielsen '93]

These numbers are ten years old, but they at least give a pointer on how things are today. If user interfaces take up a third of the weight in software reviews, then it should be given a rather high priority.

## Challenges for HCI

One big problem with HCI is that it is hard to measure the effects of it. It is very rarely that someone gets a chance to do a project both with HCI methods and without them. Most differences can be, if not proven, at least explained with other reasons.

Initially there is also a cost involved with a HCI approach. There is need for more people in the development team, which will cost money. There is also a need for end users to put time into the development process – time that can be hard to find. If the development team is located far away from the end users, more costs will be lurking around the corner.

Finding users that are representative for the planned end users can prove difficult too. In some projects the development team hires unemployed people to test and evaluate systems and interfaces. This costs money but it is then fairly easy to acquire the people needed.

Another, more subtle, problem with HCI is that there is no way of knowing if the efforts are enough. Perhaps a system is developed and all of its test users loved the system. There were no interface problems at all. However, this does not guarantee that the system will work in the field. Possibly the users selected were not representative for the users the system is intended for. By selecting users of different level of expertise and with different backgrounds, these problems can in fact be almost eliminated. There is however no way to be sure.

Consistency can also cause problems of an unusual kind. The consistency makes users expect behaviour from the application and when these expectations are not met, the interface might fail, even though the interface was good and well planned. Guidelines and rules alone cannot be enough to build a good interface.

## Differences between HCI and CSCW

Many of the things mentioned above about HCI are valid for CSCW as well. CSCW is also user centred, in a different sense perhaps, but the main goals with HCI are the still same for CSCW. This goal would be to create the usable system, well adapted for the users and their organisation. CSCW would however go about in a different way to do this.

In the definitions of CSCW quoted above there is mentioned that the organisations too can be altered to simplify work. “...*adapting the technology to the organisation, and vice versa.*” CSCW should also “...*define, structure, and link applications, data and the people who use them.*” The methods of CSCW differ from those of HCI. The building blocks available to the two fields differ vastly.

## Methods of CSCW

Working from a CSCW perspective means to get to know the users, as well how the users interact and are organised. This can be accomplished in several ways. CSCW is influenced from many different fields. It uses terms from organisation theory, cognitive psychology, linguistics and computer science and therefore also borrows various methods from these fields. The methods here are the most commonly used and talked about. These methods aim to not only to study the users but also how the users are organised and how they cooperate.

### **Ethnographical study**

An ethnographical study lets the person who performs the study to be immersed in the work place where the study is performed. This person's goal is to observe the work and social situation in its natural context. The study is performed in the user's normal environment with as little influence as possible. The observer usually spends quite a lot of time observing the users as they go about their work. The amount of time spend on a location varies with the complexity of the work, but typically this time is measured in weeks.

In the first steps of the study the observer usually only observe. There is, of course, a need of introduction to the users and efforts to make the users relaxed about having someone there to observe them. The goal is not to have any influence on the users or their work. Later in the study the observer interacts with the users, asking them on how they do certain things, why they do them, why they do not do other things and so on.

The goal of the ethnographical study is to learn the different roles users have, how these roles interact and are organised. This knowledge will help the researcher to isolate problems found in the work place studied, and hopefully, to find solutions to these problems. An ethnographical study is best performed in the early stages of development of larger systems in order to map the needs of users.

Ethnographical studies are sometimes done covertly. This is usually not advised due to the ethical problems that arise, but is sometimes the only way to perform a study. It is normally hard for the observer not to have any influence on the users if the users feel that they are being monitored. Normally this influence decreases to an acceptable level and the study can most often be performed overtly.

### **Contextual inquiry**

Contextual inquiry is another way of getting to know user behaviour in their normal context. It is usually less ambitious and is performed in significantly less time than the ethnographical study. The interviewer identifies the end users of the system and performs interviews at their normal work place. Typically several persons with similar or the same work tasks are interviewed with this method.

It is very important that the inquiry performed at the interviewed person's normal work place. To put the interviewee in his or hers normal context is the very basis of the method. This way the interviewee can show how work is done and give a better view of the important parts of it. The interviewer can also see the work, and will have a better view of the work. Many persons who try to describe their work tend to give little attention to the parts that are easy and a lot of attention to those who are complicated. The interviewer should be more interested in the parts that are important.

### **Types of cooperation**

There are different types of computer-based cooperation. With some systems you must work simultaneously to cooperate, while others do not need this. E-mail can be seen as computer-based cooperation and work can then not be carried out simultaneously. One person has to write and send the message before the receiver can read it. If the two would use a chat program instead, the receiver could read what the sender wrote instantaneously, without delay. Their work would then be simultaneous.

A similar distinction can be made with geography. Some systems require that the users are located on the same place, other do not. Program systems can therefore be said to bridge time and/or space. A common way to describe this is with the following matrix:

	One Site	Multiple sites
Synchronous Communication	Multiplayer Computer games	Electronic conference systems
Asynchronous Communication	Document handling system	E-mail

*Fig. 5, Different types of cooperation*

It can be difficult to place an application in only one of the quadrants. When e-mailing a file to someone else, the person might be working on the very same site, and therefore the application did not bridge space at all, or many of today's document handling systems allow users access the systems remotely.

#### **Asynchronous or synchronous communication**

Asynchronous communication includes systems that do not provide several users to work simultaneously on the same information. This includes most applications that we see today. If several users are to use the same data, they work on it one at a time, and coordinate this work via some other communication channel. Data are then read over networks or sent between users via, for instance, e-mail.

Examples of synchronous applications are conference systems, text editors that allow several users to work simultaneously, multi player computer games.

#### **One site or multiple sites**

Some applications provide cooperation even though those who cooperate are not located in the same office, or even the same city or country. The most commonly used application of this kind is probably e-mail. More and more applications are adapted to support wide area cooperation, usually via the Internet.

### **Shared information space**

The definitions of CSCW talked about a shared information space, or a shared environment. This does not say that it has to be accessed simultaneously or not, but simply that it has to be there. The shared information and the way it is organised is an important part a well working system.

When having all data available on the local area network, it can be regarded as a shared information space. Having files available on the Internet or perhaps a database accessible from all workstations are other examples. Most systems allow several users to use the same data. Often it can not be edited by multiple persons simultaneously; some users will only be capable of reading

the information if someone else is editing it. This is more due to problems implementing something else.

If work is distributed geographically, it will today most likely be implemented to use the Internet for communication. This raises questions of data security and integrity. Some sort of access control will probably be needed. Access control can be vital for a system but can also be found to be limiting by the users.

Encryption is not a fail safe solution to keep data from reaching competitors, or other parties, but at least it makes them work harder for it. It will stop the curious person who by accident got to see the information, but on the other hand; that person is most likely not a big threat in the first place.



## Method – Learning the industry

The method chosen for this thesis is interviews paired with a literature study. Since the product models based on IFC aren't finished there is little experience from the use of these. Many of the interviews have, because of this, a sort of "what do you believe of this" character. Little results are today available that indicate if the product models will commercially successful. Most researchers agree on that there are potentially large savings that can be done, and that product models are a good way to solve the problems.

### Interviews

The choice to base the thesis on interviews was taken because the size of the work. No contextual inquiry or ethnographical study was deemed possible due to shortages in time. To choose interviews and not questionnaires was because of the fairly limited actual experience of the persons interviewed. Only a part of them had experience with use of IFC and it was thus important to explain the questions to receive deeper answers.

### Who was interviewed?

The interviews were conducted with persons holding key positions in today's process and some who that work with related areas, such as education, research or standardisation. The key persons of today's process are the same persons who are expected to have key positions in the new process, why those persons chosen are intended to represent potential users. Some have not been working with the systems at the moment, but have influence over and knowledge of today's process. The focus of the thesis has been on the planning and managing phases of the process and this is reflected on the persons interviewed.

Interviews have revolved around how work is carried out today and what each participant thinks of the changes to his or her step of the process. Problems of the process and work in general have also been discussed. The answers given from these few persons are of course not representative for the whole industry. The companies that the interviewees are employed by have been rather large, which is not very representative for the industry. The idea of using these interviews was also a way to test ideas on someone. Having someone that had the perspective of the industry who could discuss suggestions and ideas was worth a great deal and it would have been impossible to find the same information through literature study.

The interviews covered fairly few persons, too few for making accurate conclusions, but lack of time prohibited further interviews. These interviews will at least give some sense of direction for continued work; and provide some idea of the situation.

The interviewees were selected through searching Internet. Some was also found through other interviewees. It was difficult to find building managers that were willing to be interviewed and its unclear why. It is possible, though unlikely that this has affected the results of the interviews. About fifteen building managers (companies) declined being interviewed before one was willing to participate.

### Alternatives to interviews

There are alternatives to interviews that could have contributed to the thesis. Each method has its advantages and disadvantages and the choice was made with this in mind.

### **Questionnaires**

A questionnaire is better at providing numerical results based on a larger selection of people. This has the advantage of covering a larger part of the industry and therefore makes more accurate predictions. The problem with them is that the questions will suffer in precision. It is difficult to predict which one of these two methods that will yield the better result. Today there are few people who have tried working in the new way and this leads me to believe that the result from the questionnaire would suffer from this. Many questions are also speculative, and that type of question does not suit questionnaires well.

The questions of a questionnaire must be straightforward, and easy to respond to. This is not only so the people answering the questionnaire can understand the question but also so that the answers can be compiled properly. The answers best suited in this form of survey are in forms of numbers, prioritising statements or having the respondent to agree or disagree with statements. This, as the answers must be compiled properly.

On questions where respondents are given the opportunity to write their opinion, answers tend to be short, and only seldom does someone fully expand their reasoning. These answers can be a good pointer on issues but are themselves not good for drawing conclusions. These answers are also near impossible to compile.

Another advantage with interviews is that the interviewer knows that the answers given are honest. With questionnaires there is always the risk that some of the respondents do not answer the questions seriously and this might influence the accuracy.

In retrospective a questionnaire that asked questions about how many the firms know about the new process, IFC, and ITBOF would have been valuable. The reports from ITBOF that looks into this, IT-Barometern, does not ask questions regarding the new process, as specific as would have been desired. The opinions of the people that are supposed to participate in this new process are very important. If they all believe it is too complicated or expensive to be of any use, then the process will fail.

### **Contextual inquiry**

Contextual inquiry could have contributed to this study, because it provides a better view of the work being done. The reason why this was not made was due to lack of time. Even though the inquiry itself only takes a few hours it requires preparations and analysis. Since the goal was to cover the whole process it was important not to emphasise a special step in the process, inquiries would have to have been made with all the key functions in the process. Preferably inquiries should have been made at companies of different sizes as well, and this takes far too much time.

### **Literature**

The literature chosen for this has been somewhat varied. Not only does it cover CSCW, but also the participants of the construction industry, ITBOF documentation and the idea of product models (primarily STEP). This has proved to be a problem; there are simply too many things to look into when looking at such a big process as the one of building a house. Being a student of CSCW and HCI gave me no head start at this process. Much time has gone into learning about the construction industry, work of architects, engineers and building managers.



The material from ITBOF has proven valuable but since this thesis aims to objectively investigate the process I have tried not to base too much fact from what ITBOF has written. Even though the ITBOF project has been done as scientific work, many of the organisations and people in the project have commercial interests in the outcome. Many of the corporate reports have been almost of an “advertising” character.

This thesis does not penetrate as deep as desired. It covers the entire process but only superficially. It can be seen more as an overview of the research that can be done.

### **IT-Barometern**

IT-Barometern is survey made as a part of ITBOF. It has so far been done twice, once in 1998 (1998/1999) and once in 2000 (2000/2001). The survey aims to map the use of computers and IT in the building industry in Sweden. This thesis uses these two reports to represent the attitudes of the industry. The interviewees cannot be seen as representative of the whole industry and answers differs from company to company, depending on size, geography, tradition and so on. The two reports will give a better view of the industry when it comes to quantitative data of the industry.

The surveys covers such things as computer availability in the office, computer use, what Internet connection is available, what type of software is being used, how companies would prioritise in IT development, what is good and bad with their current IT systems, attitudes towards changes, and so on.

In the first report 2778 workplaces were asked to participate and the result was based on 636 answers to interviews and questionnaires. In the second 1307 had been asked to participate and was based on 641 answers. It was made so that the results of the first and second could be compared and trends could be observed. Some questions were altered as a result of evaluations of the first report. For instance more options were added to questions where the respondent were to prioritise advantages and disadvantages of IT usage. The two reports are however still comparable.



## Results

The interviews provided a good insight on how the participants work together today and also provided a way to view different sides of the same problems. The interviews offered few surprises, the persons interviewed mostly agreed with literature. Some answers showed that much prejudice exists within the industry. Both the architects and the engineers claim to have much better and deeper knowledge in IT and computers than the others. Both of them also claim to be better at using new computerised tools.

### The cooperative process

This is a description on how the new process in the construction industry could end up and what is proposed by the ITBOF. I have chosen to refer to this process as the cooperative process since this cooperation is its leading star. The information flow for the cooperative process is taken from the old ideas of Integrated CAD from the early eighties. Some of the problems of the industry could be solved with a new process and its information flow, however most likely all of them cannot; but a change in the work process does provide an opportunity to change other things as well. The cooperative process and its new tools should try to support these other changes as well.

One of the main ideas of the process is to make the information flow more efficient. Today most of the participants have sub optimised their part of the process, which unfortunately leads to a less efficient total process. Information having to be retyped or redrawn is a common problem. Each time this is done, a risk of errors is introduced into the plans, or accuracy being lost. The way the cooperative process intends to solve these problems is by reusing information. All information in a project is saved in a shared database, the shared information space. This database can be a file, a traditional relation based database, or practically in any other form. The form of this is not the important issue of the process.

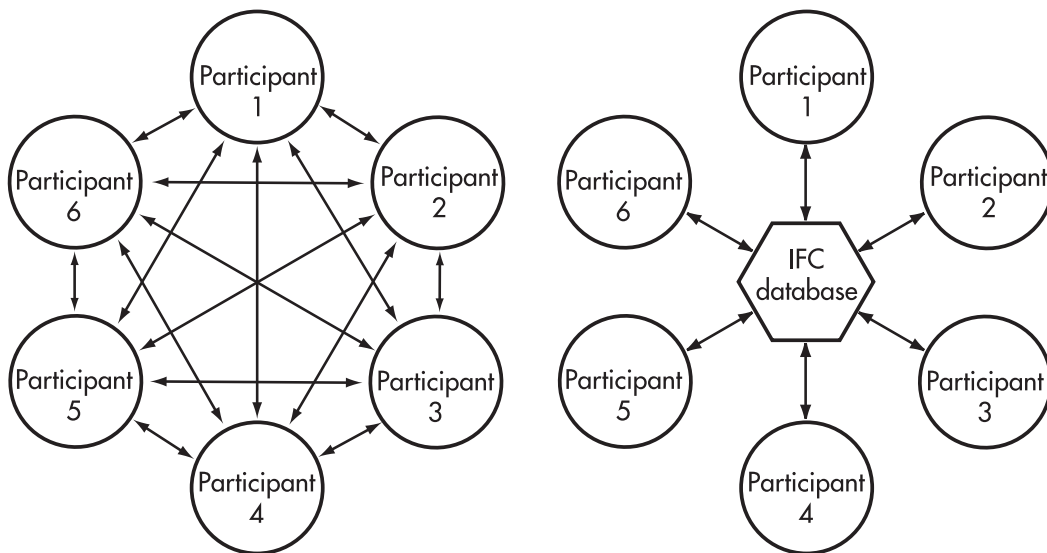


Fig. 6, Information flow today and based on IFC.

Instead of working locally on a workstation and then send the results to the other participants, all information can be stored at one place (see fig. 6). Each participant can then remotely access the data and make alterations to their respective areas.

In the cooperative process, architects start by making the functional description of the building. This work is much like the work today. One difference is that the architect can choose building elements from a database and must work in 3D. This database holds the elements provided by the material manufacturers.

Each engineer then adds his or her information to the existing, specifying the exact technical solutions. At the same time as the construction engineer starts working on the building, the electrical engineer can start working on his part. The electrical engineer adds electrical wiring, outlets, light sockets and so on. All of his building elements are attached to the functional elements put there by the architect. If the architect then decides to move a wall, due to some other reason, the electrical outlet is moved along with the wall. Still the electrical engineer would have to look at the change, to make sure it is still working the way it is supposed to. This saves time, compared to drawing lines, and to manually keep track of the changes.

During the work of the engineers simulations can be made for lighting, ventilation, temperature, how fire would spread and more. This will help build a better building by trying out more options. When modelling goes faster and objects are easy to edit, more simulations can be carried out. This then leads to the possibility of optimising the final solution. If testing a less expensive solution to see if it still meets the requirements is easier, large costs could be saved. Customers will receive better adapted technical solutions as a result of this.

In a first step the construction workers would work in the same way as they've done before. Paper drawings and descriptions would be extracted from the model and distributed to those who use them. In a not too distant future, the entrepreneurs and construction workers could be using the same 3D model directly instead. This would simplify alterations of plans since they then can be updated instantaneously. There have been attempts to do this already, but so far no solution has proved to work fully.

The building managers would still need to hire someone separate to create the reference model. This would be done using IFC based software and the documents from the original plans could be imported to the new model. It is today not possible to use the construction plan since these almost always are edited during the actual construction phase. The building ends up not looking exactly as the original plans described.

The new process would involve the same participants as the "old process" with some minor changes. A participant must be responsible for administrating and coordinating the work around the common database. This involves administrating rights and providing support as well as making backups and to guarantee data integrity. There are several participants who could do this, and there are probably other persons who could do this too, that are not participants as of today. Some roles in today's process will be reduced to something else. The purchasing phase will change since the amounts of material needed for the buildings can be automated to some level.

The finished model, updated so it is a valid reference model will contain large amounts of information. This information is updated and supplemented in accordance with the work of the building managers during the lifecycle of the building. It could become a part of the document handling system.

## Computer security

Data security is not a big issue for the industry. None of the interviewees had ever experienced an intrusion nor heard about it. There were some rumours at one firm but no one believed it was someone from the outside who did something wrong. Since almost every building is unique it is near to impossible to copy a technical solution from another building and the companies of the industry therefore trust their competitors not to steal data.

Acts of sabotage is the only feasible threats according to the interviews, but no one of the interviewees believed that it ever happens or will happen in the future – Not from a competitor at least.

In IT-Barometer there is a question where the respondent is asked to rate thirteen (in the first survey there was eleven) perceived negative aspects of increased use of IT. In the first survey, decreased security was placed dead last. In the second survey it had climbed up to the eighth position. During this time the use of IT has increased and perhaps awareness of security issues has increased with it. The survey gives no indication of this.

Architects and building managers had some concerns for some of their customers. Some customers might have high security arrangements and those customers would probably like the building manager to keep the reference model to himself. The architects sometimes have projects where the customer is interested in special security arrangements to make sure no one outside the architect's office will ever have access to the plans.

For building managers who use the IFC models as a part of the document handling system, the aspects of data security differ. If a small part of the building is to be altered, it would involve risks to give complete access to all information in the model. Giving temporary access to certain parts of the model should be preferred in cases like this. Another way would be to extract the interesting parts of the building to an external file and send this to the engineer who is to alter the building.

To fully realise this system there will be a large need of administrative work surrounding the database. If architects, engineers and other consultants are to access the database remotely, they will all have to have a login in the database. Since these projects run over a few days, weeks or months, each engineer will be involved in quite many projects. It will probably be a good idea to find some digital login procedure with signatures or cards to aid those working in these projects.

Since the threat today is perceived as small a simple user name and password could work fine. Password distribution is not a problem since the project group has meetings where the participants meet. Each person will however have many passwords, one for each database. If users can't choose their own password many will write them down. If they can choose their own passwords many will select the same for all projects. Either way the system will suffer from poor security.

## The industry today

This chapter looks at how far the industry has come in the areas of IT and computer use. It is an important part when trying to evaluate the industry's chances of successfully integrating the new process into the everyday work.

### **Computer supported work**

Both of the IT-Barometer surveys clearly show that the larger corporations have a higher computer and IT usage. All questions that show differences between corporations of different sizes show that larger corporations spend more resources on computers and IT. This is not at all surprising. A larger corporation has better chances to support its employees both with hardware and software support. A larger corporation also has better chances of educating one person and then having this person teaching or helping the others when it is needed. Some say that the knowledge of an organisation is larger than the sum of the knowledge of the individuals in the organisation.

In IT-Barometer 2000 the overall number of persons in the industry that uses computers was 88 percent. Most of the people not using computers work at workplaces with less than nine persons, primarily entrepreneurs and in material manufacturing.

Both the engineers and the architects interviewed claimed to be better at using computers than the other. According to the surveys engineers have come the farthest in integrating computers into their work. Architects have come long too, but there is a difference between these two. Architects can easier work by hand since their work is better adjusted to this. Interviews have also said that the architects have a more hierarchical structure that is making changes to work processes slower. Since the engineers are less bound by tradition it is likely that they can alter their way of work faster.

Building managers are using computers, but not to the same extent as the engineers or architects. The building managers interviewed had an architect contracted to update reference models for them. This is common arrangement among building managers. Building managers also work differently from the other two. Work is more centred around the documents and not as much in the plans.

Entrepreneurs are probably the ones using computers the least today. Since entrepreneurs do not create information but actually build the buildings, this is not strange. Plans are today paper based, so there is simply no use for computers. Billing, communication and other administrative tasks are computer based for entrepreneurs.

### **IFC situation**

Most areas of the process have some software application that uses IFC at least partially. The software is today not ready to support the process as described in ITBOF documentation. A few projects have been completed to test IFC within ITBOF. None of the pilot studies have so far managed to cover all aspects of the process; they have simply shown that each tested part works. Tests that include several steps have been carried out, but still no project has tested all steps.

Today there exist many applications that use IFC partially, or are compatible with IFC. Some architects and engineers use IFC based software today for their part of the existing process. The bigger benefits of IFC are however only rarely used.

In the area of managing buildings the use of IFC has not gotten far at all. Few applications exist and the interests from building managers seem too small. It is probably too soon for any commercial use of IFC based reference models, since no entrepreneurs and few engineers use it yet.

### **Architects**

I have heard different numbers on how many architects use IFC based software today. It varies between five and fifteen percent with ten being the most common number. There seems also be some confusion regarding what is IFC based and what is not.

The architects that use 3D models often have to convert their drawings to 2D before sending it to the engineers. To model in 3D still saves time for the architect, some say as much as 30 percent. This is of course good for the architect, but the bigger benefits as software compatibility, reusing information, linking information as so on are still not taken advantage of.

According to IT-Barometern, 23 percent of the time spend by architects on planning the building was spent on making drawings by hand. The other possible answers were various CAD tools. This is of course an average value. Many of these persons work only with CAD tools, and some work only by hand, and some use both. 12 percent of the time was spent using Archi-CAD which is an IFC compatible architect CAD tool.

It is important to remember that some parts of the work done by architects include sketching. There are some systems for doing this directly on a computer, but most architects prefer to do this by hand instead. Systems like DDDoolz [de Vries Jessurun van Wijk '01] attempts to provide computer based 3D sketching tools, but these systems have so far not been used by architects to any wider extent. Pen and paper is the dominating design tool today, and will probably be used for a long time to come.

Today about 65 percent of the architects have Internet access from their own computers. The rest of them have access from a shared computer. This number is important when considering about having everyone working towards a shared database. Connecting more users to the Internet is today not a large cost if the technical knowledge exists in the office. Hiring someone to manage networks and computers as well as handle support for users is however costly. Especially for small firms which are the ones without computers and Internet access today.

The difference for architects in the new and old process would be that they have to work in 3D when they make the final drawings. 3D modelling comes with greater need for education and training, but considering the amounts of time that could be saved it is said to be an easy choice.

The traditional role of CAD coordinator for architects in projects is uncertain. This might be better to be done by the database administrator, whoever that will be. It is possible that the architect will have that responsibility in some cases, but only larger companies will have the possibility to do this. Database administration and management are qualifications usually not found at an architect office.

### **Engineers**

The number of engineers today that use IFC based software is uncertain. Among those who do, it is almost only used internally and they do not benefit from the cooperative process. The value of 3D modelling itself is great enough for the engineers who previously had problems with collisions in their plans, to start using IFC based tools. Magic CAD has been used by the interviewed engineers who used IFC.

The engineers that use 3D model often receive 2D drawings from architects manually convert them into 3D drawings before working on them. When both architect and engineer use 3D, 3D

models are sent, but this only rarely occurs. The models sent between them are often only the volumes of walls, floor and ceilings; information such as what kind of wall it is, materials and so on are not sent along. Often the engineers give away traditional 2D, paper based drawings once they are finished.

In IT-Barometern 2000 it is reported that 11 percent of the time spent in the planning phase is spent while making drawings by hand. It is the same question asked to the architects as referred to above.

### **Material manufacturers**

I have heard of no material manufacturer that does provide IFC structures for their elements. Many manufacturers do provide their elements as 2D CAD drawings and textual descriptions that describe the classifications and details.

### **Building managers**

Building managers are the directly involved participants that use IFC the least. The computer use among building managers mostly covers the parts where no drawings are used. Many reference drawings are still paper based, and those that aren't are almost only in 2D. This might be because the building managers are the last link in the chain and will not benefit from the use until the other participants can handle their respective parts fully.

The building managers cooperate with entrepreneurs who are contracted to make changes and repairs to their buildings. These are usually smaller jobs than constructing the buildings in the first place and it is reasonable to assume that it is generally done by smaller companies. Smaller companies are using less computer tools than larger corporations, so it will probably take longer time for them to adapt the use of IFC, if ever. This lessens the benefits for the building managers to use IFC for their reference models.

Building managers have a great need of document handling systems. Preferably standardised ways to organise and structure documents. The number of documents created during the life cycle of a building is incredibly large. Document handling systems are being looked at in another sub project of ITBOF. The need of it is great among building managers.

Today there are a few specialised applications for building management as well as administrative applications for parking management, key management and so on. These tools are today not using IFC, in fact they do not use the plans of the buildings at all.

Building managers use reference models on a daily basis, but often only to read it. Changes to the reference model are carried out either by architects who are contracted to do this or in some cases done by someone at the building manager's office. It is not uncommon that someone specialises in this, since CAD work is far from what building managers usually work with.

Some building managers perceive electronic plans as a problem, since they are formatted in a way that is tightly bound to a specific software system. If the building manager has several buildings the formats of the reference plans might differ. Since the buildings have much longer life than the average computer system there might be problems with having a computer that can read these formats in the future. The systems that hold these plans have also been rather expensive to build and maintain and they rapidly become outdated by the fast developments of the computer industry.



## Discussion – Effects of the new process

Using IFC changes the very foundation of the work process. IFC requires a closer integration between the participants, leaving less room for other ways of work. Today a surprisingly large percentage of the drawings are hand drawn. Hand-drawn plans can be used side by side with an IFC database but many of the benefits of the IFC structure would then be impossible to gain. The positive sides of IFC come first when all participants use it. The advantages of reusing information come first when there is information that can be reused.

### 3D instead of 2D

IFC plans are 3D representations of building blocks. Traditional 2D plans are significantly less sophisticated. Simply a large amount of lines, that by a human can be interpreted as a part of a building is very hard for a computer to understand. 3D models can easily be interpreted by a computer and this is a large step forward. All the requirements of a building could be given to the computer who could check that the model meets them. Making simple controls that two building elements do not collide is a great improvement compared to the line based tools.

Today there exist tools that can simulate how a fire would spread in a model. It is possible to write applications that simulate how smoke would fill rooms and other spaces. By testing this before buildings are built disasters could be prevented. These tools are not finished or reliable enough yet, but the tests seem promising. On a line-based system these simulations would be near impossible to perform.

One part of the architect's work has been to put measurements on the plans. This can now be automated, eliminating errors due to errors in that sub process. If entrepreneurs use computers on site, they could have the system tell them any measurement whenever they were interested in them. The amounts of material that will be required can also be calculated more exactly when the computer understands the objects. The process of deciding how much material to purchase is difficult and it is usually only an estimate. By having better estimations, resources can be saved.

Changes to the model can more easily be made to 3D models than to 2D structures. The modular structure of objects simplifies editing. Elements that are attached to a wall will follow the wall when it is moved. By using predefined elements the amount of errors in drawings can also be reduced. When all elements are selected from a list of possible elements it is impossible to draw an element that can't be used.

Some argue that modelling in 3D affects the outcome of the architect's work. Automation of design is then seen as something negative, which leads to repetitive buildings with standardised appearance. This, as well as the opposite opinion, is very difficult to prove.

NOVEL AND UNIQUE ARCHITECTURAL FORMS, WHICH WOULD PROBABLY NEVER HAVE BEEN DESIGNED BY TRADITIONAL MEDIA, ARE BEING DESIGNED BY COMPUTER BASED SYSTEMS? A GOOD EXAMPLE IS THE GUGGENHEIM MUSEUM IN BILBAO, DESIGNED BY FRANK O. GEHRY.  
[Bourdakis, Charitos '99]

The interviewee believed that 3D modelling would have very little or no influence on the appearance of the finished building. The computer is simply just another tool, – with its own advantages and disadvantages. One interviewee put it like this: *“You can make ugly buildings both with and without them (computers)”* [translated].

## User testing

The use of IFC provides new possibilities to be working more user-oriented. When building computer systems it is important to show prototypes and images instead of descriptions and diagrams [Nielsen '93]. People who are not trained within a field will have much more difficulty understanding this kind of information than professionals would. It is therefore important to display information that is accessible for the users. When talking about computers programs, pictures of interfaces of even paper mock-ups can be utilised.

The construction industry often says it is the only industry in the world that cannot build full-scale prototypes. Much of the effort lies in the actual construction of the building. User oriented work is however important here as well. In the book “User participation in building design and management” [Kernohan et al. '92] these problems are discussed. There are other ways to perform user testing other than to build the building and test it with users.

By having a 3D model of the building, pictures of the finished building could easily be made. Images with good quality and realistic appearance can be created. This makes it is easier to show future users of the building the proposed appearance and evaluate it early. It is likely to assume that residents of buildings have similar problems as computer application users to understand descriptions and plans and realistic colour pictures are far easier to understand. VR presentations can easily be made as well as interactive programs that can be run on a standard personal computer. The use of IFC reduces the cost of prototyping and makes user oriented work easier.

## Flexibility within the standard

Since every application that is to use IFC for communication, is limited to what IFC supports, a big factor is how good the standard supports its users. Having a standard that is too open can lead to problems with incompatible software, if only subsets of it are implemented. A too narrow and strict standard leaves too little room for creative solutions which is usually needed when doing complex modelling. The strengths of a standard are to provide just the right amount of flexibility.

Size and ambition of the software requires different things from the standard. If the standard is too complex it will limit the number of corporations that are willing to support it. If it is too simple and small, it will probably not be good enough for the large projects that use all the advanced functions.

According to IT-Barometern 2000 the most negative aspect increased use of IT is “*constant demands for upgrades of software and hardware.*” It is rated number one of thirteen various aspects. In 1998 it was only beaten by “*too high investment costs*” which was number two in 2000. The IFC standard cannot change to often or demand that all participants will use the latest release, because the participants are unwilling to upgrade at such a high rate.

The current version of IFC (2.0) is not the final version. Work on the next version is already under way and there will probably be more versions after the next one as well. Version 2.0 can most likely support the industry for now, with the functions it provides. Once the standard reaches the level where most of its users are fully satisfied the rate of new versions will go down. Or in other words: As long as there are significant improvements to the standard at each release, there will commercial reasons to upgrade the software.

The influence this will have on the process is that it will alter the flexibility of the industry to

what IFC allows. The standard is very open and flexible so it should not be a problem in the end. Earlier attempts to model the world around us has however proven to fail, given enough time for the world to raise its demands.

## Supporting the users in communication

A very important aspect of software that involves many users, are how users communicate. Communications can be categorised in several different ways. Christopher Allen [Allen '90] clearly divides communication from conversation and emphasises a proper balance between these two. Communication is when facts and information are relayed between two persons as opposed to conversation that holds a more social function and lacks a specific goal.

A system that has too much communication tends to be narrow and dry. It is usually perceived as very goal-oriented and can be stifling to creativity and innovation. On the other hand, a system that has too much conversation is often chaotic and ineffective. A properly balanced system gives its users the possibilities to communicate in both forms.

In the case of application for the building industry the informal communication channels can be possibilities to comment solutions and objects and making these comments visible. In order to support cooperation and communication other users should be made visible. Communication does not have to be integrated into the application themselves, but other users and participants should not be hidden, as it is common that applications do.

When it comes to cooperation in projects, most communication is handled through project meetings. This is a good thing since it provides the possibility for formal as well as informal communication. It is a semi social meeting where the participants meet face to face. If no support for spontaneous meetings exists, there might be problems with cooperation [Kraut et. al. '90]. Even though the information that is spread in a meeting can be spread in other ways too, the model of having project meetings should be kept in projects. The cost of them is small compared to the social benefits and positive effects on cooperation.

## Responsibilities

The construction industry is highly regulated, and it is important that only the person that is responsible for a part can change that part. This clashes a bit with the idea of attaching details to functional elements and then have the details move around with the functional objects. This is better described with an example: A functional wall is created by the architect, and then the electrical engineer adds an electrical outlet on the wall, and wiring inside the wall. The electrical wiring is the responsibility of the electrical engineer, and should only be altered by the engineer. If the architect needs to move the wall, he or she cannot, because the wiring would have to move as well. The situation creates a deadlock. The architect cannot move the wall because there is an electrical outlet on it, and the electrical engineer cannot move the wall at all. This could be solved in several different ways.

The software should at least provide a function to find who the architect should contact, and how to make this contact. It could be as simple as a notation of a telephone number for whoever is responsible for electrical wiring. A more complicated solution could be some sort of chat function, perhaps a voice link. If both of them are connected to the database simultaneously, they could communicate directly and solve the situation. Otherwise a system like e-mail could function just as well.

The architect also could simply move the wall, and along with it, the wiring. When the electrical engineer logs on to the database the next time, he or she would be prompted to approve the change to the wiring, or given the opportunity to redraw the section.

Both way, there will be a need for approving changes and electronically signing changes, or documents. There are several standards for this today, so this is not to be seen as a problem.

## Other industries

So far there has been no project that tries to change the structure of an entire industry as ITBOF attempts to. Other industries has however been changed by introduction of new IT systems. The graphical industry is a good example. The changes of that industry were fundamental and many of the changes were not seen as positive by the industry. [Grafiska företag i mediabranschen – vad gör vi nu? (Graphic companies in media – what do we do now?) '99]

When desktop publishing and other digital layout techniques became popular at a large scale much of the job previously done by people in the graphical industry was taken over by their customers, leaving only the actual printing jobs. By sending information to the printing presses in digital formats such as PDF (Portable Document Format) there was little need of many of the traditional roles. At the same time as many people became “obsolete” there was a big demand for people who was trained in the new technologies. There is also an increased need for investments in competence instead of physical property such as printing presses or other machinery.

Many of the people used to be the experts of what they where working with had a hard time when their traditional tools and methods disappeared. Being reduced to a novice from an expert is not easy. Those in the industry who were the best at adapting the new methods were those who just had started. Younger people usually have better knowledge of computers and the only ones that were trained in the new methods were those who've just left their universities or colleges. The industry has been described as traditional and hierarchical and there have been reports of many conflicts due to this.

There are positive effects for this industry as well, but one should be aware of the impact of larger changes to an industry. By many of those who worked in the industry it meant that they either had to quit or retrain to do something else.

There are similarities between the graphical industry and the construction industry but also differences. The construction industry is not as homogeneous as the graphical industry. Some of the problems for the graphical industry can probably be found in the cooperative process as well. Various traditional roles will disappear, and be replaced with new, and there might be a shortage of properly trained people. It is easy to draw a parallel to the hierarchical structure within the architects to those who used to be working with the printers.

For the graphical industry the changes lead to a more efficient structure and work processes. Some of the people who were working in the industry felt that they've lost much on the changes. The changes also led to changes in the market. New competitors entered the market and the companies discovered that there were great possibilities for differencing within the market. It is likely that similar effects will be noted in the construction industry.

## Problems with an open format

For the software corporations the introduction of a product model could be seen as something negative. A common data format will seriously reduce their possibilities of keeping customers. Many corporations use a strategy called lock-in to make sure their customers do not switch software solutions. Lock-in works by making sure the customers switching costs, i.e. the cost of switching to another system, are high enough to keep them from doing so [Shapiro Hall '99].

Lock-in can be done in many ways; by keeping all data in a specialised format, which is incompatible with the competitors'; by having a specialised user interface that makes it difficult for customers to relearn another system. Another way is to introduce a feature that the competitors lack so customers can cannot switch systems without losing the feature.

The proprietary data formats of today are a typical example of Lock-in. This is negative for the customer, who cannot change software tools as he or she pleases or cooperate with others who use different tools. Lock-in provides stability for the software suppliers but they do not have much choice other than to implement a non-proprietary format when customer's demands support for it.

Software corporations will most likely try to lock in their customers in new ways, since it is a standard strategy when dealing with information based products. Even if they manage to do this, the building industry has gained something very important with the implementation of IFC; the possibility to cooperate and communicate with others.

Overall it is a negative thing that the large software corporations lose on the introduction of product models. They therefore have an incentive to make the new process fail. Their part of the building industry is however to provide the software tools their customers want. If some of the bigger companies support this (such as AutoDesk who was among the corporations that took the initiative to start the IAI) others probably will follow.

There are of course companies that do welcome IFC. For the smaller software developers, the introduction of IFC could be a very good thing. Their market expands as many customers use systems that are compatible with theirs, providing a potentially large market. A non-proprietary format expands the market for smaller applications; it will be possible to sell the product to all participants that have a need for the tool regardless of what software system they are using.

## What problems could be solved?

Some of the problems for the industry today that were listed above could be solved by the introduction of an IFC based process. But likely not all of them can. The list of problems were: Limited perspectives, incompatible software systems, incompatible data formats, poorly adapted software systems, double work, collisions in plans, experiences from earlier projects, novice customers, poor calculations on material usage and poorly updated reference models.

Some of these are apparent that they will be solved if the new software systems will be used. Incompatible software systems and incompatible data formats will probably be solved, poorly adapted software systems too. The problem of collisions in plans is already solved with 3D CAD based software. Material calculation cannot be used and the problem of double work cannot be solved until all steps of the process are used fully, but the tests carried out so far seem promising.

The problems of the limited perspectives itself will most likely not be solved by the change of process. The participating companies will probably not start caring for one and another to much because a few new software systems. The negative effects of it will however be lesser. Information sharing is the key to the cooperative process and what will lessen the negative effects of the participants' limited perspectives.

If experiences from one project will be taken into consideration in the next one is hard to predict. With the IFC models available it might be easier to go back and look things up, but it is hard to say if this will actually be done. Construction plans for a building falls under the influence of copy-right laws and it is hard to know if engineers will have access to them after the project is finished.

Customers will probably still be novices to the same extent in the future. Possibly will the new process make it easier for the project management to manage to project more efficient in the future but it is also hard to say.

Likewise it is hard to say if reference models will be updated properly in the future. New projects can likely be done in the new manner within just a few years, but the reference models for older buildings might not be converted since it costs money to do so. It seems likely that reference models will not be converted until the building will be rebuilt. Even if they are converted it does not necessary mean that they will be updated in the future.

## Building element databases

Databases with building materials that are following the regulatory classification system BSAB exist. They can be used today but there is a request from architects and engineers that material manufacturers provide IFC models for their products; models that can be used inside the building model instead of being linked to an external resource describing the part. If a door manufacturer could provide IFC data for each of the doors he provides it would simplify the selecting process.

This could also be a marketing solution for the manufacturer. If it is easier for architects and engineers to browse or search their products it will likely improve the chance of their product being chosen.

## Empirical work

There have been tests of various parts of the process. Some have been conducted as a part of ITBOF and others have been conducted independently. One test project aimed to work with pre-cast concrete units [Karhu '97]. This project involved a 95-apartment residential building that was planned with the use of a product model approach. The project showed that both the architect and the pre-cast concrete unit manufacturer could be save time. There were also positive effects for the concrete precast manufacturer who now could provide cost estimates earlier in the process, accuracy in data were increased, and it was predicted there that product models would lead to shorter design times and also fewer mistakes in the process.

## Simultaneous work

Much research has been done on user interfaces where people work simultaneously on the same data. Most of the research projects have investigated more simple applications, such as text editors, source code editors and similar products. Many of them have shown good results, but of course, there have also been some negative effects.

Simultaneous work within a large 3D structure is possible to build today, provided a high bandwidth connection to the data from each participant is available. It would then be possible to reduce the time it takes to design the building, and therefore speed up the process.

One way to implement simultaneous work in the process would be the following: Each participant who currently is connected with the database could see any other participant also connected. It would be easy to display what part of the structure another user is looking at and also see what changes the person is currently doing. Changes that are made at one workstation would immediately be visible to all other connected workstations.

Using this kind of technology has some apparent advantages, higher design speed, possibility to make changes later in the project, closer cooperation with other participants, looser limitations on when the different participants can start and finish their work. It is also far more complicated to build, and therefore has a higher risk of malfunctioning. It will also require more infrastructure, in the form of high bandwidth connections to a central server, as well as the server itself.

This solution is probably not possible due to the high complexity. It requires that IFC handles this and today there are no plans for this. Many of the applications that use IFC today, do not use real time graphics in the way it would be required, and the cost of rebuilding these applications are probably too great.

## Sequential work

The alternative to simultaneous work would be sequential work. This will work as well, if only a bit different. In a completely sequential scenario, an order of work must be issued before the participant could start working. The architect should of course start, and make the functional description of the building. After the architect is finished, the construction engineer could start working. Then the other engineers would do their work in sequence, and every time a change has to be made, this change has to propagate through all participants that have done their work earlier.

This might sound cumbersome, but in smaller projects this might work just fine. When the object is a one-storey residential building, most work has to be done sequentially anyway. The architect has to create the functional walls before the electrical engineer can start on his work.

One big advantage with sequential work in this case is that the lesser need for infrastructure. All information could be saved to a single file that is sent, perhaps by mail or e-mail, between the participants. There is no need for a server and the cost of server administration.

Data security would be reduced to making sure data is safe when sent between the participants. This could be done with encryption. There is also no need for passwords, or the handling of those.

## Semi-parallel work

There are other ways to organise the work within larger projects. By locking a certain part of the structure, work can be semi-sequential. By dividing the building into several smaller sections, one user could work at the time in each of these sections. Work would in each section be sequential, but several people could work simultaneously on the building. This is how most projects are done today. In larger projects where several architects or engineers have to work

simultaneously, the typical solution is to make several different sections of the building and have them drawn separately.

This approach is best suited for larger projects, where a lot of work has to be done. The approach also adds a step that has to be done. The sections have to be created by someone and the different participants must lock or check out a section to work on it. It leads to a more complicated structure for the users to work with, and might be considered as a problem.

Similar locking mechanisms are used by software developers that handle large projects where many programmers are working simultaneously. The locking systems works but are by many people considered as problematic.

There are more ways to handle the problem of work structure, these are not as good but will work to some extent. The most obvious one the simultaneous access without the possibility to see what the others are doing. Many people that are connected to the database simultaneously as described in the first case but this time without the possibility to see what the others are doing. To get an updated view of the building you would have send for the entire structure again.

The different participants that work on the project handle different objects and work differently on the structure. There will probably not be many conflicts, and those who occur have to be solved when they do. The solution has many advantages when it comes to implementation of the applications.

## Problems with Implementation of the new process

There are some problems with switching to the new process for the industry.

### Five factors

In “Groupware and Cooperative Work: Problems and Prospects” [Grudin ‘90] identifies five factors contributing to failure of groupware.

#### FAILURE CAN OCCUR:

- IF THE PEOPLE WHO HAVE TO DO ADDITIONAL WORK ARE NOT THE PEOPLE WHO PERCEIVE THE BENEFITS FROM USE OF AN APPLICATION.
- IF THE TECHNOLOGY THREATENS EXISTING POLITICAL STRUCTURES OR CERTAIN KEY INDIVIDUALS.
- IF IT DOES NOT ALLOW FOR THE WIDE RANGE OF EXCEPTION HANDLING AND IMPROVISATION THAT CHARACTERIZES MUCH GROUP ACTIVITY.
- IF THE COMPLEXITY OF THE APPLICATION MAKES IT VERY HARD TO LEARN AND GENERALISE FROM OUR PAST EXPERIENCES.
- BECAUSE OUR INTUITION ARE ESPECIALLY POOR FOR MULTI USER APPLICATIONS.

The first factor is applicable on one of today’s problems. Those who put more time into the process, does not gain from this themselves. The profit from this extra work comes later in the process and someone completely different gains from it. Totally, the amounts of time spend on creating the information will be reduced, so for the customer the situation will improve, but the resources must be redistributed within the process.

By using IFC based applications, users automatically can reuse information created by others. It is difficult to see the economical consequences of this.



The second factor can be found as well. In some parts of the industry, primarily among architects, the organisation is hierarchical and based upon traditions. Persons who have worked for a long time as architects have the more important positions and the more creative tasks. These persons are unlikely to be the best at using the new technology of 3D modelling. It is the same problem as the graphical industry had as mentioned before; so similar situations might occur here too.

Introduction of new computer tools will probably be learned by the younger people first. This introduces problems as it threatens existing political structures within these work places. Those in the corporation that has higher “rank” will not be the ones with the expert knowledge, and this could make it harder to introduce changes.

The third factor talks about the complexity of the application, which applies poorly to the system of applications available to the industry. We are not discussing one application, but a wide range of vastly different applications. Some applications will suffer from lack of exception handling and possibility for improvisation while other will not.

The problem described in the third factor is however important. If fixing problems found in the plans, made by someone else the represent a different participant, are too difficult or time consuming, the person who found the problem probably will not bother to fix it. After all it is not his responsibility. It is easy to draw a parallel to the problems with lack of cooperation we see today, where persons only look at their own responsibilities.

The fourth and fifth factors are harder to decide if they are applicable. It does to a high level depend on “*our past experiences*” or the definition of “*multi-user applications*.” The two latter factors, if combined, can shed some light on the situation. Factor four tells us that it is hard to use a system if it differs from our experiences with earlier systems. Factor five tells us that most of us have little or no experience with earlier systems. Using multi-user applications differs from other software in how it is best used and this can lead to confusion. The problems of having poor knowledge of multi-user systems can however easily be addressed; it is only to start using and learning them and those problems will go away.

### **New technology**

The new process also includes new technical solutions and some of the participants must take the responsibility for the new systems such as the servers. The new systems include both hardware and software, and require some sort of digital infrastructure. Much of this exists today, but it is unclear who will be responsible for it. It is very hard to estimate the cost, since many different solutions are possible.

There is a cost associated with purchasing new software solutions and new hardware to run it on. There will also be a massive need for education for the involved parties. It is also unclear if the smaller companies can handle these costs in the same time as the larger ones.

The very basis of IFC is a standardised format, and it is therefore very important, that the standard is updated to be usable for the corporations involved. A large burden lies on the IAI to make sure that the standard is powerful and flexible enough to be usable, but also stable enough for software corporations to keep supporting it. Since it is a standard its primary strength is that many parties use it and that it is followed.

### **Responsibility for the database**

There are several possible participants who could be responsible for the database. This participant must also control access rights, and provide some sort of service to the other participants. This means that there is a need for high bandwidth connections to the other participants, a database server and someone who can administrate rights.

Since the database holds all plans and documents, it is very important that the database itself is never unavailable. Access to the database is critical for the other participants and must always work. This requires that those responsible for the database must be highly skilled within this area.

The most natural selection according to me would be the building manager who will have to have the same responsibility for the reference model. If the building manager would like to, it could be outsourced to someone else as well. When looking at who would have most to gain on making the process more efficient the building manager or customer would be possible candidates. They are the ones who gain the most of making the complete process more efficient.

### **The need of education and training**

To learn how to use these new systems there will be a vast need for training and education. If every aspect of a building has to be modelled in a 3D environment, everyone working with creation of the models has to have some education and training in 3D modelling and how to navigate within the models. It is hard to estimate how much time it will take to learn sufficiently to start using it in full scale. Estimations vary from between eight days up to two months for architects, also depending on how much the architect already knows about computers and 3D models. The actual figure is probably somewhere between these two values.

Before the people in the industry have learned to handle the new tools, there will probably be mistakes due to problems with handling of the systems. Often the way of learning that is perceived best is to learn from someone who already knows the subject being learnt. There are unfortunately few experienced people that work on site that can help those who need help. A large part of the industry consists of small companies, with small possibilities to have internal education.

Both of the IT-Barometer surveys the third largest perceived negative effect of increased IT use is *“increased demands of knowledge on employees.”* The question was asked regarding IT use and not IFC in particular. The need to retrain employees is however seen as a large issue by many.

The cost for education is large in itself but also keeps the people in training from working with projects that they can charge someone for. The cost of the education is then seen as even greater.

### **Lack of formal education**

In today's education in building and real estate, IT and similar topics are not emphasised at all. Only a small part of the courses given deal with it [Samuelson '01B]. Education on both high school and college level are targets for ITBOF as they aim to provide better adapted education that reflects the needs of the industry. It should be very important to have the schools teach the students to use the tools of the industry especially when the need of the industry is great.

There are a few colleges and universities that provide targeted courses in this area. This is a very important step in implementing the new process. Without skilled people that know how to use the systems, the systems are not going to be used.

## Economic savings in projects

One of the main goals of the new process is to make it more efficient than the old one. Since the total amount of time is reduced, this means that someone will lose money on the introduction of the new process. Where did the money go? Where in the process will money be saved? Who will lose money on this?

### **The architects**

For the architects the introduction of the new process would require them to retrain a large part of their workforce at a high cost. New software systems also must be purchased and also new routines must be created before they can start working with IFC properly. This will then lead to faster work with fewer errors. Faster work means less revenue unless the companies raise their rates or otherwise alter the business model.

Since the architects initially have expenses for switching to the new process, it is likely that no money can be saved in their part of the process. The interviewed architects seem more interested in selling the advanced functions to engineers and building managers rather than to see it as a natural change in the plans. The margins are today small for the architects and the customer can make rather tough demands without the architects being able to make too much protests.

### **The engineers**

For the engineers the situation is similar to the architects. On the question if the engineers are prepared to charge less if they would have better input, as fully integrated IFC models, they say that they are not. With today's business model they will do the same work on lesser time, which will give them less income. This, combined with the fact that many companies have large expenses for education and new software systems, makes it less likely that the new process will be fully implemented any time soon.

The interviewed engineers say that their model for payment is outdated and poorly adapted to today's reality. As their work is more efficient, their work should take less time to complete. The product their delivering is today of much higher quality than before. Not only are there fewer errors and collisions, but with it, it is also easier for the engineers to compare more alternatives leading to more alternatives being tested and the customer gets a better adapted solution in the end.

For the engineers the demands for their competence have increased when the tools have become more and more complex. Some engineers discuss if pricing should be based upon the perceived value for the customer rather than how many hours have been put into the project. So far no concrete suggestions to a new business model have been presented.

### **The material manufacturers**

For the material manufacturers there are potential savings. Primarily for those who make specialised elements such as prefabricated concrete elements. If they can use the product model for designing their elements significant amounts of time can be saved [Karhu '97].

For other manufacturers that do not customise their building materials, no time can be saved. The manufacturing cost is far greater than any cost related to creating descriptions or drawings.

### **Calculations of material usage**

Resources and therefore also money will be saved when the amount of material can be more accurately calculated. As previously mentioned, as much as 30 percent can go to waste. Before the introduction of IFC and automatic calculations these calculations were done manually which was both time consuming and difficult. The potential save lies not only in better calculations, but also there will be no need for someone to make the calculations.

### **Fewer errors in construction**

If overall quality is increased, fewer errors should occur. Errors discovered in the inspection of the finished building are usually solved by having the one found responsible for the error rebuild the parts that are erroneous. It can also be solved with a direct economic compensation to the customer.

With fewer errors both of these forms of compensation should decrease in numbers. Rebuilding or repairing erroneous parts are naturally costly, and so are the direct compensations. If the use of IFC reduces the number of errors some money will be saved here as well.

Errors as when the buyer deliberately purchases a different kind of door in order to save money will not be changed due to the use of an IFC based work process.

## Conclusions

There are several benefits coming from using an IFC based process that can't be ignored. The fact that it leads to fewer errors; speeds up the planning process, gives better control of the information are enough to believe in the new process. It is a better way to work, by sharing information between the participants, having the data in a format that can be understood and continuously worked on by everyone in the project; the problems of the limited perspectives in the industry can be almost eliminated.

There are however problems; not necessary problems with the cooperative process but more on how to implement the new process. Most of the problems with the cooperative process are actually problems with switching the two processes. According to the time table of ITBOF from 1997, IFC should right now be ready to be used at a large scale for all of the participants, but this has not happened; there is still a long way to go before we are there.

One of the engineers interviewed stated that:

*"The introduction of IFC is good for everyone involved"* [translated]

That company is already using IFC for modelling today and believes strongly in it. For them, the benefit of eliminating collisions in the plans was a great enough a reason to switch to 3D modelling. They do not however use the entire process, but have simply changed their own part of the process. This is a likely way for the industry to change. Architects and consultants slowly switch towards 3D modelling and IFC simply because there are benefits for them in their own part. Whenever they can they will send 3D models or IFC models between them; and when the time is right, building managers could start using IFC for the reference model as well.

These changes will come slowly however, and far from all participants will use IFC. Even though it was twenty years since 2D CAD became available for a wider use, still today 23 percent of the time spent by architects on drawing, are drawn by hand [Samuelson '01A].

It is easy to draw a parallel to the introduction of computers in general. At first a typewriter is replaced with a word processor, the drawing board is replaced with a CAD tool, fax messages are replaced with e-mails. Each step of the old way of work is replaced with an electronic version of the same sub process. In the next step each of the new tools starts to be integrated with one and another. The CAD plans are e-mailed to other participants along with descriptions written in the word processor. At first each step is replaced and then the steps are integrated to a new process.

It is likely that the building managers are the last to switch to IFC based software, since it is harder for them to fully utilise the benefits until the other participants switch software. The engineers and architects can themselves make profits from switching while the building managers are more dependent on the others.

### Introduction of changes

In the paper "Groupware in Practice" the authors [Bullen Bennet '93] talk about how systems are introduced to those who are going to use it. The same system was introduced to two different groups of users. The first group was told that the system was a new system that was supposed to be tested and evaluated and the decision if the system was to be used permanently had not been taken. The second group was told that this was a new system that would seriously improve the work of the users and that they were supposed to use it in the future.

After five years the two group's attitudes towards the system were investigated. The first group still regarded the system as something that was being evaluated and tested while the second group had fully integrated the system to their work. The way the two groups used the system were different and it was explained with the differences in the introduction. Therefore the way in which new groupware is introduced into the work group will influence the ways in which they are used.

The building industry is a much more complicated group of people than these two work groups but the attitudes towards the changes will probably have great influence on the outcome. Today the pilot projects are presented as prototypes and tests of the technology, even though the applications used in these projects are "finished." There is a risk that the new process will be regarded as something new, and somewhat abstract and diffuse for a long time. This, unless it at some point is introduced as a working process; a process that is more efficient, gives higher customer benefits and will raise the competence in the industry.

In order to make this new process succeed, software developers have a difficult task ahead of them. To successfully implement cooperative software it is simply not possible to take the old single user software and sell it as groupware. The best way to implement groupware and software aimed at groups of people is to take the old, well working single user software and add group support to it [Grudin '94]. To help the changes for the industry, developers might have to provide more adaptive solutions than before. Cooperative software can be very difficult to sell as of the shelf products [Ibid] and often there is need for adaptations and customised solutions. It is important to remember that the software used here must be very adaptive since the organisation changes from project to project. The participants are not the same in the next project as they were the previous.

To introduce this new software to the industry might however take more than well-working software. In order to have acceptance among users, there might be further work for developers to help the users work with the new software and its new features. Many users have poor knowledge and little experience from groupware and usually it is hard to generalise from single user software. Therefore users might need help to use the new software effectively.

### **Business models**

Today's business models are adapted to today's process. These are by many considered not fitting for the cooperative process and these must be changed in the same pace as the process is being changed. Some participants have large expenses in order to fully support the new process and this will slow down the changes.

Today the consultants of these projects are charging based on how many hours are spent working on the project. If those who have implemented the new process can do the same work in lesser time, changes to the business model must follow. The engineers interviewed talked about charging in other ways but had no concrete suggestions yet. Changes are on the way at least even though it may take time.

When looking at the change from a more qualitative perspective, all participants are going to have new expenses due to this change and no participant is ready to charge less than they are today. If the new process proves to be more efficient these expenses are in fact investments that surely will pay off.

### **Information regarding the changes**

If the new process is to be used by the industry, the industry must know more about it. Today there seem to be little knowledge about the changes. One interviewee referred to this as “*an attempt to set new standards for file formats*” [translated] without being aware of how that would influence the industry. Some of the interviewees have made remarks of that there has not been enough information from the ITBOF project and that key persons in the industry have not even heard of IFC.

To successfully introduce the new process to the industry, all participants need to know the possibilities, limitations, costs and implications of the new technology. This comes from actively seeking and informing the participants. The engineers and architects that use 2D CAD or some other form of 3D CAD are not that hard to inform of the benefits of IFC based 3D models. The building managers are harder to reach since they do not always use the systems themselves.

### **Who loses on the new process?**

Those, whose jobs will be replaced with new roles, will probably feel as if they have lost on the introduction of the new process. These people are for instance the ones that today make calculations on material needs for buildings, those who have specialised in advanced aspects of 2D CAD, and others who have put a lot of resources into the current way of work. Most of these persons have a deep knowledge in the industry and can probably find other tasks within the industry. Someone must for example operate the automated procedure.





## Recommendations – How to implement the process

When thinking about switching to the cooperative process there are a lot of facts to consider. In this section a set of guidelines are presented. These guidelines are based on my findings in the literature and opinions presented to me in the interviews. There are naturally different guidelines for architects/engineers, building managers and customers. Since building managers often acts as customers the guideline written for customers applies to those building managers too.

### Guidelines for architects and engineers

1. Make the change slowly. Start by changing to a 3D CAD system that supports IFC and learn it well. All well written software system that provide 3D CAD can also “flatten” the models into regular 2D plans, this is important since it provides the possibility to work in “the old way” as well as cooperation with companies that do not use IFC. It would be wrong to throw oneself into a new process and therefore isolate oneself from the old way of work. If other participants linger too long, it will be very expensive to be first in the field.
2. Get a super-user. The best way to learn a system is to learn from someone who knows the system, while doing real work. This someone is on many workplaces called the super-user. With this approach it is not necessary to send everyone in the workforce on expensive training; it might be sufficient with the basic course, provided there is a super-user who can help the users when it is needed.
3. Use IFC whenever it is possible. If the firm is capable of modelling in 3D it should be preferred since it reduces the amounts of errors. When the staff has learned to use the systems well, it will also save time.
4. Cooperate with others that use IFC. Many benefits of IFC are best utilised when several participants use it together. This could help in lowering costs in the projects and therefore the possibility to landing the contracts. Ask other in the projects if data can be exchanged through IFC.
5. Try new business models and evaluate them. The business models of today is said not to be suitable for use with 3D models. The benefits should be shared among the participants, and those who make investments must be allowed to make them pay off.
6. Create and respect routines for data security and passwords. When several companies work together it is important that everyone involved respects the rules and routines. Networks provide great possibilities for communication but can invite random attacks.
7. Backup means security. When working with computers information could be destroyed by accident or otherwise lost. It is just as easy as spilling a cup of coffee on the drawing board, with the slight difference that with computerised system, someone might spill coffee on the entire archive with all work ever done on the firm. Backups effectively protect against this.
8. Do not stop spending money once the system is paid for. It would be a disaster if large resources were spent on buying new software systems and ending up not using them because there was not enough money for education and training. This is a situation that was not uncommon when CAD was introduced in the early eighties.
9. Do not invest in systems that will not be used. There are a lot of talk about server solutions that will help coordinate work around the IFC model, but these require a lot of work. Make sure that you have the knowledge on how to use them, and keep in mind that such knowledge costs money when purchasing such a solution. Depending on the outcome of the change, customers or building managers might already have the software, hardware and knowledge for these servers.

## Guidelines for building managers

1. Choose an IFC based system for reference models. An important part for the building managers is the possibility to link large amounts of documents to the models, and parts of the models. The possibility to integrate reference models with the online document handling system has great potential of providing easy access to the information.
2. Do not convert old paper based or CAD reference models until you need them. The conversion process is today expensive and not foolproof. It is better to wait and let the systems that do this evolve until they work fine.
3. Have someone at the firm learn 3D CAD. It could be a good idea to learn 3D CAD work for a building manager. The education is considered expensive by many, and the need of this for the building manager is limited. Some training in navigation in the models are required if the firm will use IFC for reference models.
4. Make the system secure. Data security is according to many in the industry not a big deal, but the consequences for data loss should be considered as a catastrophe. Backups of models are essential for this to work and there is little merit in saving money on this. Intrusions are rare according to the interviewees but should still be considered as a danger. Deliberate sabotage might come at any time.
5. Invest in the databases. Being in control of the shared database lies within the building managers' interest. It is practical to have this inside the company walls, but there is also a great danger to it. Since the shared database is critical to the work of everyone in the planning phase and those managing existing buildings, the database has to be stable and well maintained. This requires knowledge and time (and therefore money) to keep the database in this state.
6. Do not stop spending money once the system is paid for. It would be a disaster if large resources were spent on buying new software systems and ending up not using them because there was not enough money for education and training. This is a situation that was not uncommon when CAD was introduced in the early eighties.

## Guidelines for customers

1. Ask for IFC. The customer is the one in the process that have the greatest potential of making gains by using the new process. Reducing planning costs by having the architect and engineers use IFC based software should be easy. It will also most likely help reduce costs in the purchasing phase too.
2. See the initial costs as investments. There are potential savings for using an IFC based process, but it must be allowed to cost a bit too. Initially the costs of architects and engineers must be covered. By letting the architect and engineers charge more per hour, since the IFC infrastructure costs money for them, they might work faster and produce lesser errors. Work can also be accelerated, allowing them to charge for fewer hours.
3. Use existing infrastructure. Since the building manager must have a database or at least have hired someone to manage a database to use the IFC-based software, this database might be usable during the planning phase.
4. Do not over-invest. Every company that ever builds a building do not need their own database and administration for it. If the company will only occasionally builds a house, hire someone to administrate the database for each project. There are great costs at stake if the database or its information is corrupted.

## Future directions

This thesis have given me a deeper insight in the building industry, both as it is today and what it might be in the future. My image of the building industry has changed during this work, and so has the focus of my interest. Some areas that should be covered in a thesis such as this one were not covered. This comes mostly of the lack of time and lack of previous knowledge.

The industry is today highly regulated, and there are many laws and rules that must be followed. This thesis does not at all look at these legal issues, and perspectives. I do not know what laws and rules that must be updated to fully allow the cooperative process, or if any changes has to be made at all. To investigate this would contribute much to changing the process, since legal aspects effectively could stop any attempts to switch to the new process.

It would also be good to investigate the industry's attitudes towards these changes. It is a risk that those engaged in ITBOF are the one that are most interested in the changes, and that they are not representative for all of the industry. The best way to map the industry's attitudes towards the new process would be to include it in IT-Barometern and to make a third survey. It would also give better support for studying trends in the industry's computer and IT usage.

This thesis aims at covering the entire process, forcing it not to penetrate deep enough into the situation any of the participants. Doing so would of course be interesting and could probably provide some interesting results. The view of the industry used in this thesis is also rather crude, for instance the work and needs of the different kinds of engineers are likely to differ too. Here they are presented as on group with similar work tasks and needs, simply because they have the same role in the information flow.

In the long perspective it could save a lot of money to let the construction workers have direct access to the digital models, instead of the large papers of today. It would make sure that everything is updated at all times, the time schedule functions could then be fully utilised. It would also allow customers, building managers and other interested parts to follow the progress of the production phase. The development and testing of these systems are also in the interest for the new process. Some on site testing have been performed with this but the systems are far from finished.

A new business model could be very valuable for the industry. It would therefore be useful to investigate what other models have been tried and then evaluate these. Measuring quality of the material from the new process with material with the old process could be a good starting point.

The guidelines in chapter nine should be tested, evaluated and improved.



## References

- Al-Timimi K. and MacKrell J. (1996) STEP: Towards Open Systems CIMdata ISBN 1-889760-00-5
- Allen C. (1990) "Groupware communication and conversation" Published in Applied Groupware fall of '90, <http://www.alacrityventures.com/> last visited 2003-06-30.
- Andersson N. and Ekholm A. (2002) "Vetenskaplighet – utvärdering av tre implementationsprojekt inom IT bygg och Fastighet 2002" Technical report ITBOF
- Baecker R. M. (1993) *Groupware and Computer-Supported Cooperative Work: assisting human-human collaboration*. Morgan Kaufmann Publishers Inc San Francisco ISBN: 1-55860-241-0
- Bannon L. J. and Schmidt K. (1991) "cscw: Four Characters in search of a context" Edited by Baecker R. M. *Groupware and Computer-Supported Cooperative Work: assisting human-human collaboration*. (1993) Morgan Kaufmann Publishers Inc San Francisco ISBN: 1-55860-241-0
- Berg S. (1999) "Virtuell CAD. Slutrapport" Technical report Berg Arkitektkontor AB.
- Bourdakis V. and Charitos D. (1999) "Virtual Environment Design – Defining a new direction for architectural education" Conference paper eCAADe99
- Bullen C. V. and Bennet L. J. (1993) "Groupware in Practice" Edited by Baecker R. M. *Groupware and Computer-Supported Cooperative Work: assisting human-human collaboration*. Morgan Kaufmann Publishers Inc San Francisco ISBN: 1-55860-241-0
- Coyne R., Newton S., McLaughlin S., Jumani A., Sudweeks F and Haynes D. (1996) "Computers in Practice. A Survey of Computers in Architectural Practice"
- Dyson E. (1992) "A Framework for Groupware" cited by Baecker R. M. *Groupware and Computer-Supported Cooperative Work: assisting human-human collaboration*. Morgan Kaufmann Publishers Inc San Francisco ISBN: 1-55860-241-0
- Ellis C. A. Gibbs S. J. Rein G. L. (1993) "Groupware some issues and experiences" Edited by Baecker R. M. *Groupware and Computer-Supported Cooperative Work: assisting human-human collaboration*. Morgan Kaufmann Publishers Inc San Francisco ISBN: 1-55860-241-0
- Grafiska företag i mediabranschen – vad gör vi nu?* (1999) Grafiska Företagens Förbund, Technical report Grafiska företagens service AB
- Grudin J. (1990) "Groupware and Cooperative Work: Problems and Prospects" Edited by Baecker R. M. *Groupware and Computer-Supported Cooperative Work: assisting human-human collaboration*. (1993) Morgan Kaufmann Publishers Inc San Francisco ISBN: 1-55860-241-0
- Grudin J. (1994) "Groupware and Social Dynamics: Eight Challenges for Developers" University of California Irvine
- Johannesson C, Levin B. and Hauch P. (2003) "IT Bygg och Fastighet 2002, Slutvärdering – Hovedpunkter fra analys och interview" Technical report ITBOF

- Karhu V. (1997) “Product model based design of precast facades” Licentiate Thesis, Royal Institute of Technology Stockholm
- Kernohan D, Gray J. and Daish J. (1992) *User Participation In Building Design And Management* Butterworth Heinemann ISBN 0-7506-2888-x
- Kraut R. E, Fish R. S, Root R. W. and Chalfonte B. L. (1990) “Informal Communications in Organizations; Form Function and Technology” Edited by Baecker R. M. Groupware and Computer-Supported Cooperative Work: assisting human-human collaboration. (1993) Morgan Kaufmann Publishers Inc San Francisco ISBN: 1-55860-241-0
- Nielsen J. Usability Engineering (1993) Academic Press
- Noack R. (2001) “Converting CAD Drawings to Product Model” Licentiate Thesis, Royal Institute of Technology Stockholm ISBN 91-7283-067-0
- Nyman H. (2002) “Informationsflödet i en framtida byggprocess – baserat på produktmodeller” M.sc. thesis Royal Institute of Technology Stockholm
- Reed M. and Hall E.T. (1975) *The Fourth Dimension In Architecture* Sunstone Press ISBN 0-86534-033-1
- Samuelson O. (1998) “IT-Barometern 1998 Läget för IT-användningen inom byggande och förvaltning i Sverige” ISBN 91-7170-334-9
- Samuelson O. (2001A) “IT-Barometern 2000 En undersökning om IT-användning i bygg- och fastighetsbranschen” ISBN 91-631-1499-2
- Samuelson O. (2001B) “Building and real estate related IT in higher education in Sweden An investigation of education in strategic IT” Technical report ITBOF
- Schneiderman B. (1998) *Designing the User Interface* Addison Wesley ISBN 0-201-69497-2
- Shapiro C. and Varian H. R. (1999) *Information Rules* Harvard Business School Press ISBN 0-87584-863-x
- Tarandi V. (2002) “Implementering av produktmodeller baserade på IFC och BSAB”
- de Vries B, Jessurun A.J. and van Wijk J.J. (2001) “Interactive 3D Modeling in the Inception Phase of Architectural Design.” Eindhoven University of Technology

## Appendix A – Technical terms

**CAD** – Computer Aided Design (Drafting). The name for techniques that use computers for designing technical systems or parts of systems. CAD can be both 2D and 3D oriented.

**IFC** – Industry Foundation Classes. The standard that specifies a production model for the building industry.

**IAI** – International Alliance for Interoperability. The organization that creates the specifications of IFC. The organization has a sub organization in Sweden as well as other countries or regions. <http://www.iai-international.org/>

**STEP** – Standard for the Exchange of Product Data. STEP is an ISO standard for different forms of product description. Originally it was for mechanical details but has expanded to many new areas.

**EXPRESS** – The file format used in STEP and IFC. It is an ISO standardized language that provides data portability between different systems.

**BSAB** – Byggnadens Samordning AB. The Swedish version of an ISO standard for classifications of building elements. It is currently being administrated by AB Svensk Byggtjänst. <http://www.bsab.byggtjanst.se/>

**ITBOF** – IT Bygg och Fastighet 2002. A Swedish five year research project that aims to make the building industry more efficient. [www.itbof.com/](http://www.itbof.com/)

**IT-Barometern**. The name of two surveys that map the use of computers and IT among the building industry in Sweden. The survey has been made twice (1998 and 2000).

**HCI** – Human Computer Interaction. This is a research field that focuses on learning about how to make humans understand computers and vice versa.

**CSCW** – Computer Supported Cooperative Work. This is a sub field of HCI that limits its perspective to system that has multiple users.

**VR** – Virtual Reality. Computer-based stereoscopic 3D presentation of often none-existent environments.