TAMPERE UNIVERSITY OF TECHNOLOGY

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DIRECT MODELING IN GLOBAL CAD ENVIRONMENT

Master of Science Thesis

Examiner: Prof. Asko Riitahuhta
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ABSTRACT

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The thesis has been done as a part of modelling toolkit development for Metso Mining and Construction business. The aim of this work is to study the new modeling tools, opportunities, risks, and compare them to existing practices. The target is also to examine the suitability of tools, at a general level to the product development process, and to identify the target company's processes where the tools can add value.

The work is divided into four parts. At first existing design tools are described. This part clarifies the existing design tools and highlights the problems that current practices have. Then features and use of the new direct modeling methods are presented. Studying the tools is already partly new information as the theoretical basis of this topic is still narrow. The third section compares the existing and new modeling tools with each other in order to identify parts of the product development process, in which new methods could be useful. The last part researches the use of direct modeling tools in product development process and describes the best practices in the target company's processes.

Research indicates that in the target company's activities can be found many processes, which can be enhanced by the use of direct modelling. Introduction of new practices have to start from the user level, which causes that the entire global company operating practices change swiftly. Therefore, awareness-raising and training is essential to achieve the objectives. Solutions found are mainly local level changes which may also facilitate global collaboration of the company.

TIIVISTELMÄ

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Diplomityö on tehty Metso Mining and Constructionin suunnittelutyökalujen kehitystyöhön liittyvänä osana. Työssä tavoitteena on selvittää uusien mallinnustyökalujen mahdollisuuksia, riskejä ja vertailla niitä olemassa oleviin toimintatapoihin. Tavoitteena on myös selvittää työkalujen sopivuutta yleisellä tasolla tuotekehitys prosessiin ja eritellä kohde yrityksen toiminnassa ne osat, joissa työkalut voivat tuoda lisäarvoa.

Työ jakaantuu neljään eri osaan. Ensin selvitetään suunnittelutyökalujen kehitys pisteeseen, jossa uudet mallinnustyökalut tulivat mahdolliseksi. Tämän osuuden on tarkoitus selventää olemassa olevaa suunnittelutyökalujen käyttöä ja nostaa esiin ongelmia, joita nykyisissä toimintatavoissa on. Tämän jälkeen esitellään uudet suoramallinnus menetelmät sekä niiden piirteet ja käyttö. Työkalujen uutuuden vuoksi esittely on osaksi jo tutkimista, koska teoreettinen pohja näiden suoramallinuksen esittelemiselle on vielä kapea. Kolmannessa osassa vertaillaan olemassa olevia ja uusia mallinnustyökaluja keskenään, jotta löydetään tuotekehitysprosessin osat, joissa uusista menetelmistä on hyötyä. Viimeisessä osassa sovelletaan työkalujen käyttöä tuotekehitysprosessissa ja etsitään parhaita toimintatapoja ja käyttökohteita kohdeyrityksen prosesseihin.

Tutkimus osoittaa, että kohdeyrityksen toiminnasta löytyy paljon prosessin osia, joita voidaan tehostaa käyttämällä uutta teknologiaa. Uusien toimintatapojen käyttöönotto kuitenkin pitää lähteä käyttäjätasolta, joka vaikeuttaa koko globaalin yrityksen toimintapojen muutosta nopeassa aikataulussa. Tämän vuoksi tietoisuuden lisääminen ja koulutuksen järjestäminen on ensisijaisen tärkeää tavoitteiden saavuttamiseksi. Tietoisuuden lisääntyessä myös prosessin jatkokehitys ja suoraviivaistaminen on mahdollista, kun vanhoista toimintatavoista siirrytään ensin uusiin. Työssä löydetyt ratkaisut ovat pääasiassa lokaalilla tasolla tehtäviä muutoksia, jotka kuitenkin voivat helpottaa myös globaalia yhteistyötä yrityksen toiminnassa.

PREFACE

“There is only one way to learn. It's through action. Everything you need to know you have learned through your journey.”

-Paulo Coelho

"A Smooth Sea Never Made a Skillful Sailor"

-Unknown sailor

Thanks to my Parents and Raquelita!

In Tampere, Finland, on 6 February 2015

Pauli Hakala

Pauli Hakala

CONTENTS

TERMS, DEFINITIONS AND ABBREVIATIONS

CAD:	Computer Aided Design
PLM:	Product Lifecycle Management
PDM:	Product Data Management.
EDM:	Engineering Data Management
LTDR:	Long Time Data Record
JT:	A 3D data format developed by Siemens PLM Software
STEP:	Standard for The Exchange of Product model data (ISO 10303)
IGES:	Initial Graphics Exchange Specification
B-Rep:	Boundary representation models
ECAD:	Electronic Computer-Aided Design
DFM:	Design for Manufacturing
FEM:	Fine Element Method
NX:	High end CAD of Siemens
NURBS:	Non-uniform rational basis spline. For generating and representing curves and surfaces
DMU:	Digital Mock-up

1. INTRODUCTION

1.1. Starting Point of the Work

Nowadays global design environment includes lots of different options and choices between CAD programs, design methods and file forms. In side global big company and subcontractor can be many different ways to do the things. Lots of worktime is used to solve problems in integration of these methods. Also lot of information is lost and is not used when creating solution to these problems.

In case of Metso Mining and Construction Technology there are many different methods and programs in use. That situation is causing lot of extra work, problems to adapt “design any where-built any where” method and also work that has been done twice. Long-term costs can be reduced by developing interoperate of CAD-systems.

In this work main programs to be researched are NX and its Synchronous Technology and Autodesk Inventor with Fusion technology. These programs will be 2 main tools for designer working with CAD. Subcontractors are delivering most of the models in universal formats like STEP, IGES and Parasolid. This is causing lots of problems because universal files are missing the history-tree and modelling techniques are mainly based on editing parameters in the history tree. Also migrated models in some of the Metso MCT sites are missing the history tree so editing this information can cause lot of work.
During the last few years most of the CAD-programs have got own unique direct editing or modelling tools to modify CAD-data without features or parameters. Some of the programs are still carrying history-tree with them but also there are history-free possibilities available. In the newest versions of CAD-programs these tools are available automatically and this gives man new possibilities to engineers to modify and change information in 3D-models. Some of the companies are already looking for different ways to get benefit of the new technique, so missing this step can leave big hole to the CAD-knowledge of the company.

1.2. Objectives of the Work

The first target is to get more familiar with direct modeling and history-free design environment. Objective is to find out what is the main advantage and base of technique. After having enough knowledge about new modeling methods the knowledge has to be modified to the form organization can understand it and use it.

When starting to use new technique there has to be some rules of use. This technique can give many possibilities to modify design processes and make it more efficient. One way to find out these advantages is tool-shootout process. Direct Modeling tools are tested with common modeling tasks and problems with modeling. Also advantage of direct modeling tools with migrated models and universal file formats will be researched, especially how Synchronous Technology and Fusion are working with those. Main interest is to find out how programs can use information in geometry of solid bodies and how reliable is the geometry in different formats.

When the tools and ways of using those are researched opportunities and risks can be searched. Possible opportunities can be found from areas of product development, innovation process, data sharing, handling CAD-data, engineering changes, CAD-interoperate. All those areas are also in a connection with multi-CAD global design environment. One main objective is to research how direct modelling can make global design environment and co-operation between Metso MCT sites more fluent. Biggest risks can be in the area of security issues and uncontrolled use of new tools. To avoid those threats the objective is to create rules that are eliminating possibilities of accidents and misuse. After creating rules all Metso MCT design processes in connection with direct modelling and history-free environment has to be tested and roll-out of new technique can be done.

1.3. Structure of the Work

This thesis is divided into 3 parts. In part one, a history of CAD, theory and terms of direct modelling and comparison between old and new techniques are presented. Chapter 2 will introduce the history of CAD modelling, different CAD-tools and levels of different CAD-environments. Chapter 3 will go through Direct Modelling techniques and history-free CAD-environment. In chapter 3 also different direct modelling and editing CAD-programs are introduced. Chapter 4 gives short introduction and comparison to 3D-geometry editing tools. Also benefits and problems of parametric and direct modelling tools are given.

Part two focuses on how to get an advantage and how to avoid risks of new 3D modelling tools and environments. In Chapter 5, advantages of history-free environment in assembly modelling are presented. Chapter 6 changes in drafting when using history-free environment are given. Chapter 7 focuses on PDM/EDM systems with history-free CAD environment. Interoperability of CAD-programs is presented in chapter 8. Chapter tries to give an answer to challenges of the multi-CAD environment and data transfer problems. Chapter 9 will introduce R&D process from CAD's point of view. Different steps of the process are presented and ways to improve the process with new technologies.

In part three, common design processes and sites specific characteristics in design processes are presented. Chapter 10 introduces design rules and some best practices for the new technology and also outlines the role of technology in the future.

1.4. Research Methods

Research was mainly made in Metso Minerals engineering environment. Part of the work was getting known to the processes and tools of the company. Tools and process changes were tested in Metso Minerals engineering environment and the feedback was collected from Metso engineers and other persons working with engineering applications. Because there is not much literature about the subject theoretical part of the work is based on mostly online and magazine articles. The chapter about CAD development history is based on CAD blogs, but information has been confirmed from the literature about CAD systems. Theoretical part about Direct Modeling has created by testing but idea for test targets has been collected from articles and real life cases.

Information related to development and future changes of programs and new possibilities of those is gathered from software providers and conferences. Also online webinars and lectures have been used. To name couple Siemens PLM Connection 2011 and Autodesk University are referred widely. One of the most interesting ways to gather information was open conversations with people related to CAD development and usage.

1.5. Delimitation and Readers

This study is focus on CAD environment and editing 3D-geometry. Study does not cover whole information management process. Study covers most common CAD-programs but focus is on Siemens and Autodesk products. The coverage of this study is in the use of new CAD tools and environments and the study does not cover program language of direct modelling tools. Examples are mostly from the area of mechanical engineering.

Work is primarily aimed at persons responsible for the development of CAD systems and training of the end users. The study does not contain accurate instruction for the direct modelling tools and it is not guide for the end users.

1.6. Company Introduction

Metso is a global supplier of technology and services for the mining, construction, power generation, oil and gas, recycling, and pulp and paper industries. Metso Mining and Construction Technology (MAC) is a technology and services provider, which product range covers the mining, minerals and crushed rock handling systems, service solutions and spare and wear parts. In the end of 2013 MCT employed about 9500 persons worldwide. In 2013 Metso Corporation's net sales were EUR 5,552 million euros, of which MAC’s share was 2,276 million euros. 47% MAC’s net sales consisted of the service business (Metso vuosikertomus 2013).

In 2013 Metso’s main themes were service business, environmental business and global presence. In MAC global presence means global manufacturing and services. Products are designed to produce cost-effective and flexible close to the growing market. Global presence also affects to design environments, service business and spare part business (Ainasvuori 2014).

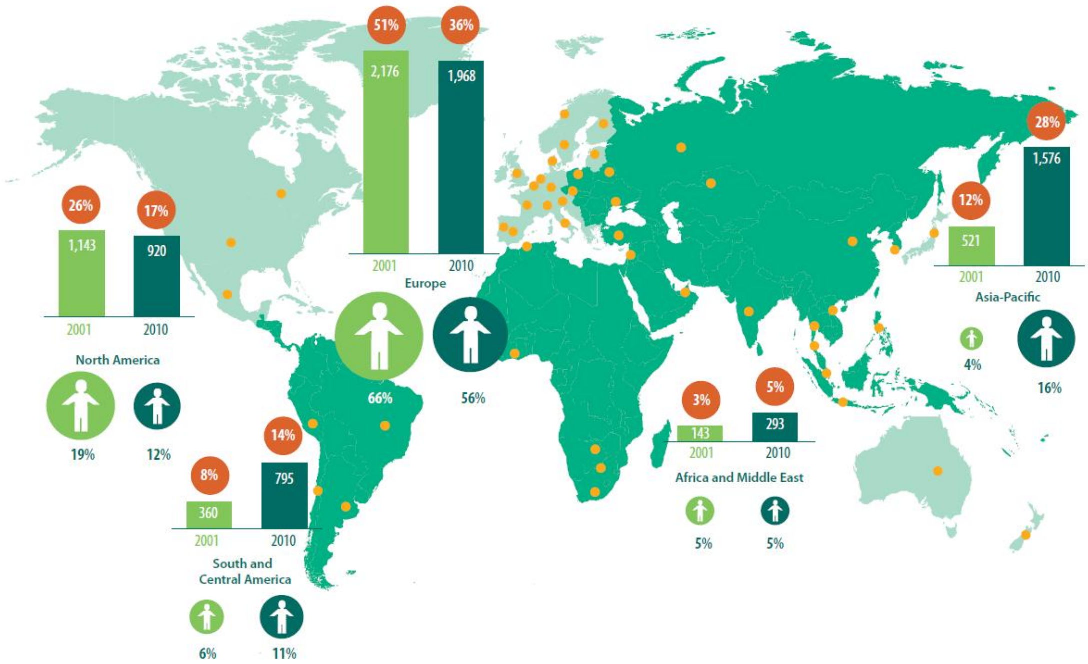

Figure 1. *Metso in emerging and developed markets. (Metso vuosikertomus 2013)*

2. COMPUTER-AIDED DESIGN

2.1. History of Computer-aided Design

3D CAD and computer technology has continued development last decades but even today much product design is still being done in 2D. Most used mechanical CAD program is AutoCAD from Autodesk. What is the reason that companies hasn't switch to 3D design by now. New designers have good skills from 3D CAD and there are many usable and capable 3D CAD systems on the markets. Also IT-infrastructure has developed to the level, that implementation of programs shouldn't be problem. So what is reason for common use of 2D in the mechanical design. At first is good to take a look at the usual transition from paper and pencil to digital product development (LaCourse 1995).

1. Design with paper and pencil, create detail drawings on paper
2. Design with paper and pencil, create detail drawings with 2D CAD
3. Design with 2D CAD, create drawings with 2D CAD
4. Create 3D models, use 3D models to create 2D drawings
5. Design in 3D, use 3D to create 2D drawings
6. Design in 3D, virtual prototype and simulate in 3D, use 3D to create 2D drawings
7. Digital product development, leverage 3D throughout product lifecycle to reduce/eliminate the need for 2D drawings and duplicated effort

All levels listed above are still normal ways of working today's engineering environments. Even somewhere design is still done with paper and pencil, some others are doing product development with little or without drawings. Understanding of the 3D as a key component in the product development processes and environment is critical when competing in product development (Kojo 2001).

Ever since designing has been done 2D has been used. Use of computers to assist design process happened only recently. Changing drafting boards to CAD took some time but once confidence with computer was gained it was not difficult move. Moving to the computer did not cause any major change to the process other than drawings were saved to the database rather than blue printing them. In this point designing and processes were actually changed only little (LaCourse 1995).

First 3D programs did not manage so well. Programs were expensive and slow and design processes were still very depend on the 2D drawings. Only a few early adopters were able to use it reasonable and the 2D was only real tool to the design work. First 3D programs were purchased to create ability to speed the process of creating 2D drawings. Even some companies realized the potential of 3D designing most were thinking that their products were so simple from the geometrical view that there is no value for them to move to 3D designing (LaCourse 1995). 2D was not the bottle-neck in designing process, but was there some value missed with this decision?

2.2. CAD Environment Stages

There are still many companies which have made the conclusion that the value of moving to 3D does not justify the cost. In this chapter benefits and costs of different CAD levels has been compared. 3D CAD has now existed over 30 years so there is lot of information to answer these questions.

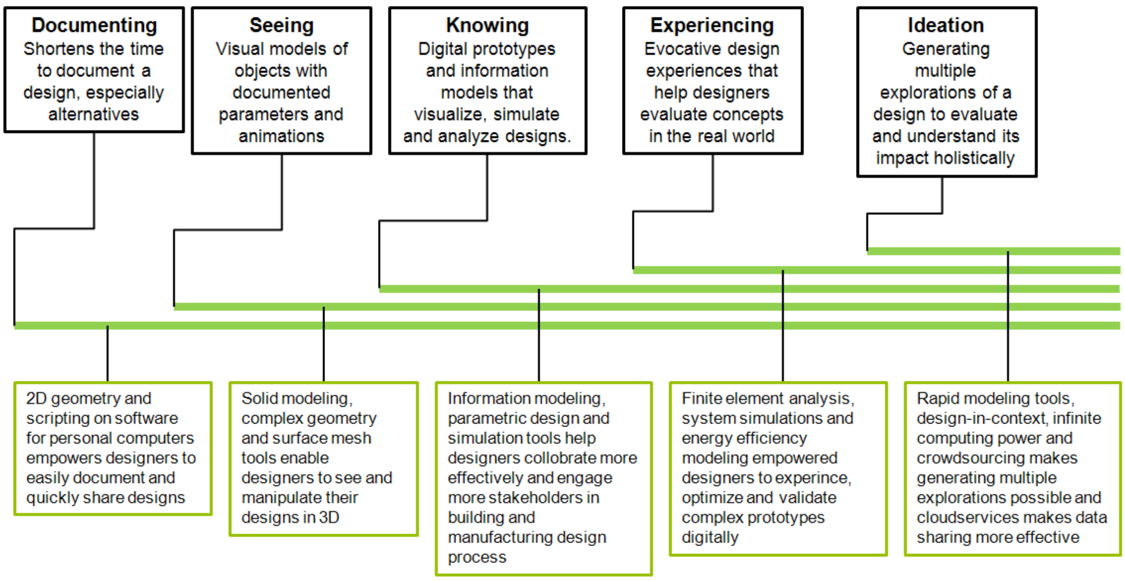

Figure 2. *CAD environment level. (Wujec 2011)*

2.2.1. Using 3D to create Drawings Faster

It is easy to prove that in most of the cases it is faster to create drawing by using 3D. Even in the simplest cases 3D model makes process of creating drawing easier. Views are created automatically and adding dimensions is faster and more automatic. With 3D representation it is easy to leverage data into the assembly design process and reuse it in the future products. Using 3D modeling to create drawings faster represents the minimal benefit of moving to 3D environment. To see the value you only need to calculate hourly rate of a draftsperson (Wujec 2011).

Using 3D to create drawings faster does not make any significant cost to process. 3D tools need to be purchased but the bigger cost will be training required when moving to

new CAD system. There may also be some cost related to the data management and model libraries. In this point when selecting a 3D CAD easy-of-use should be considered. Today's 3D CAD programs can have significant impact to design processes. New program should support also properly process and business needs. Right choice at this stage can greatly affect the future cost in the use of 3D design data (Wujec 2011).
Costs related to existing design data need to be considered at this stage also. Even today still lot of data is a form of paper drawings but more often it is electronic form. Reuse and leverage of this data brings the value to it. Value is normally related to product lifecycles and specially service business. Usually data remains in its current form even new system is purchased. Use of many different forms can increase costs when data is used or maintained. However upgrading data from 2D to 3D when needed might be good solution. Functionality to leverage and reuse 2D data is important to maintain if business and its processes requires it. In some cases selecting 3D system carefully can affect in many ways to 2D data reuse and leverage (LaCourse 1995).

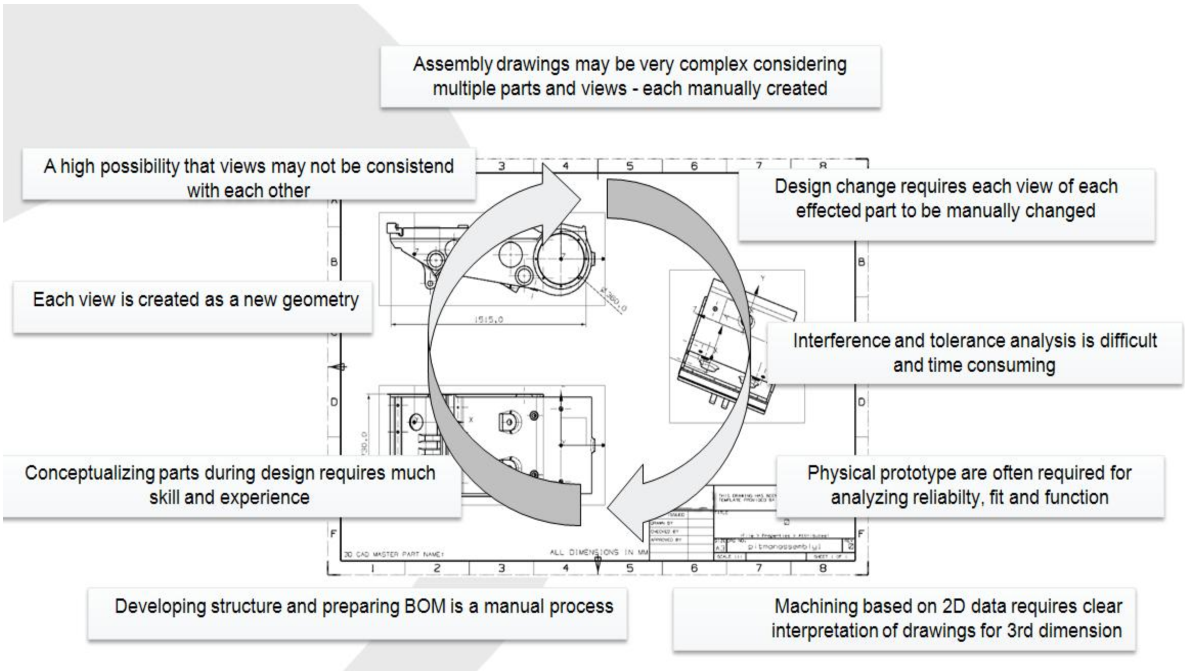

Figure 3. *Problems with 2D information*

2.2.2. Using 3D to create Accurate Drawings

At this stage value of 3D is much more than making drawings faster. Drawings are still the master document even they are completely generated from 3D model. Drawings and all the views can be generated from one 3D model and all views will exactly match the model. Possibility that incorrect drawing goes to the production is much smaller. An incorrect drawing in the production can cause lot of cost and cheapest way is to eliminate this possibility already when designing is done. The value of this stage can be evaluated from the frequency of errors related to incorrect drawings, and the cost because of errors (Kojo 2001).

At this point no additional investment for the system is required. To create more accurate 3D models and use them more effectively to create drawings and views faster is only a matter of training.

2.2.3. Using 3D to create Accurate Designs

At this stage the value of changes will get difficult to measure. At stages mentioned before drawings are created from accurate 3D models. At this point accuracy of design itself is questioned. Do the parts fit together in the assemblies? Do the assemblies work how they should and are interferences understood? 2D drawing can still be master document, but 3D models are being used to create accurate design and deeper product planning. 3D data can be managed formally by extracting BOM's and applying access control, revisions and versioning also at a part and assembly level. The value of this stage is reached by avoiding rework in the production. Also volume of change requests from the production should reduce because errors can be noticed at an earlier stage (LaCourse 1995).
At this point there are some impacts to process. More efficient EDM/PDM system is required and standard part libraries should be created. These systems need formal and disciplined management to avoid the extra cost because of the duplication. Management includes part numbering and naming with attention. Bigger issue can be changes to culture and habits that will be required of the CAD users. At this stage assembly modeling is required. There can be new advanced functionalities in CAD program and the training is required to take advantage of these features. Also there may be some additional task specific modules to 3D CAD that need to be purchased (Kojo 2001).

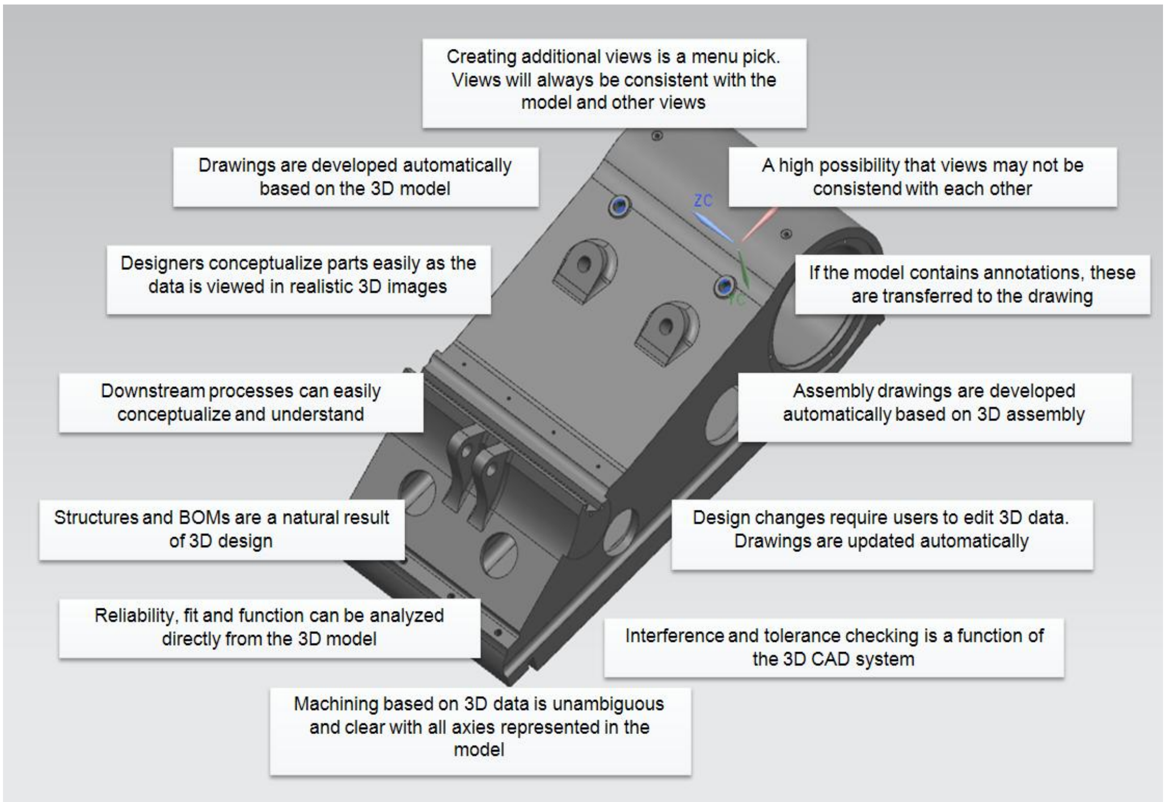

Figure 4. *Advantages of 3D modeling*

2.2.4. Using 3D to support Digital Product Development

Now the 3D model can be considered as the master. When 3D is used to drive complete product development value can be creation of highly accurate design (Pukkila & Järvelä 2005). Value is difficult to measure, but it is possible. Use of 3D data is leveraged to last throughout the product development lifecycle and maybe throughout the whole product lifecycle. Master model provides all downstream documentation. Prototyping, manufacturing, assembly tooling and CNC programs can be derived from the master model which is now the 3D geometry. Use and maintain of fully detailed drawings can be reduced and in many cases eliminate. Information management is now highly streamlined. With formal information management everyone is working on the latest versions and collaboration and information distribution are streamlined (Direct Dimensions 2012).

At this point most significant cost will be process change needed. With process change also habits and culture have to be modified, including the supply chain and partners. One of the most significant costs will be PLM that supports this level of productivity. Without well controlled PLM taking the step to move to this stage does not bring the value available. Also some other additional functionalities through the product development and productization processes will need to be purchased. Cost is greatly dependant on the product and its design cycle, lifecycle, volumes, company size, business drivers, distribution and supply chain (Wujec 2011). Close attention should be paid to find right tools for the process and business drivers. Otherwise costs can get out of control.

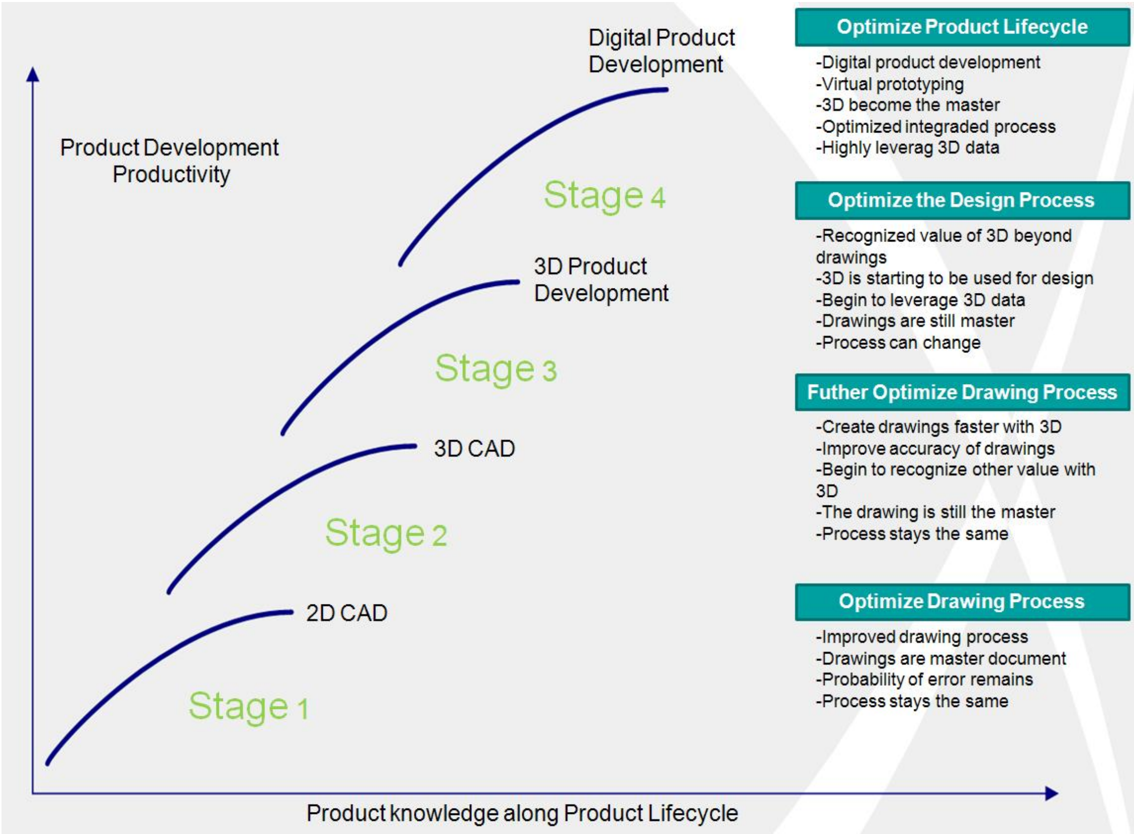

Figure 5. *CAD environment stages. (Wujec 2011)*

2.2.5. Summary

The value of 3D can be summed easily. By using 3D potential duplication and errors are reduced. Increased leverage of existing data can result improved innovations, better quality and reduced change process time and time-to-market. Once 3D geometry is created and formally managed you can create documents needed from it. Duplications can be avoided through the product lifecycle. “The basic value of 3D is in doing something once and leveraging it to the maximum possible”.

Before making any decisions related to designing tools, culture, process and business should be carefully considered. Technologies and tools purchased must enable process and process must support business drivers and objectives. It is really important to start with right tools to have the minimized impact to process and to avoid extra cost.
Taking the step towards digital product development can realize significant business benefits. The necessary technologies already exist and there are even standards that have been defined to help companies make the move.

2.3. CAD Technology

Before moving to CAD tools it is reasonable to take a look at things behind. A company's business drivers and key business objectives are driving and guiding processes which are supported by tools and technologies. Choosing and developing right tools processes can be improved. Improved processes can be delivered to the business drivers.

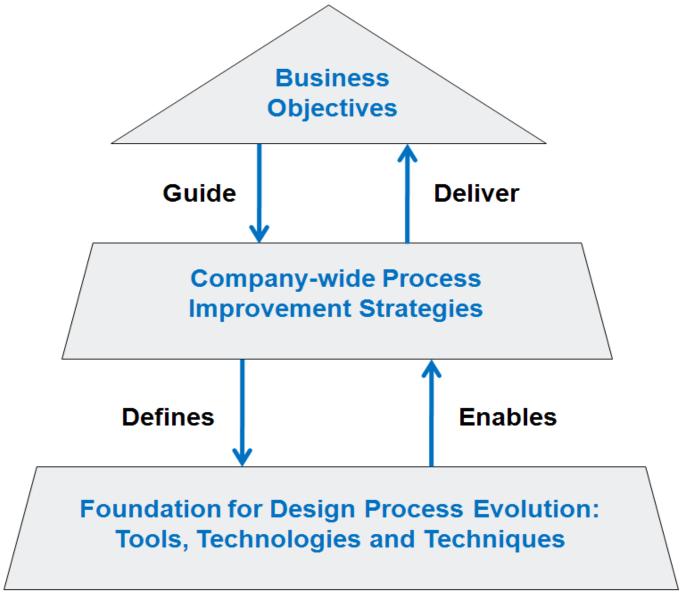

Figure 6. *Design tool/process development. (Wujec 2011)*

Power of the IT organizations has grown a lot last years. This is happening because companies are becoming more dependent on computers, internet and programs. Today companies IT organization is something totally different than ”support organization”. What is the role of IT department in this process? They are delivering and supporting technology and tools. In this case they should be well aware what tool best supports the process. To have that awareness they should understand the product development process and key business objectives. Also success with tools that impacts product development should be able to measure. Still the range of involvement can be from complete and dedicated “support”, to complete and dedicated “control”. Best option is healthy balance between IT and product development.

2.3.1. Types of CAD programs

There are many different types of CAD programs. Different CAD systems require the user to think differently. Use of the system and the way of design can be different between different CADs. Still today most common CAD is 2D. There are also many open source and free programs available. These programs provide an approach to the drawing process without strict rules of scales and placement. This information can be still used when doing the final draft (ASME 2012).

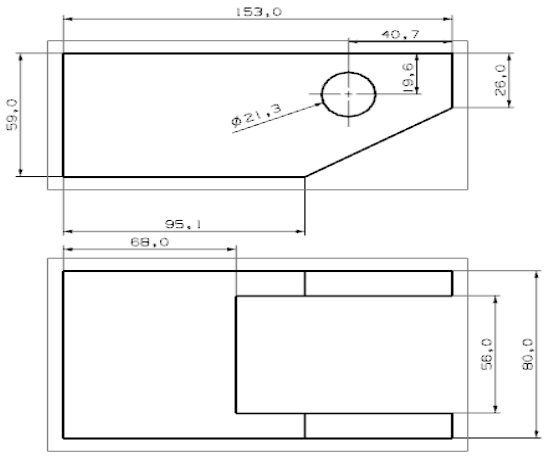

Figure 7. *Part information in 2D*

3D wireframe is just an extension of 2D drafting and it is not often used today. Lines have to be inserted manually and the final product does not contain automatic mass properties. Many higher generation CAD programs allow users to do 3D wireframe models as a view to the final drawing (ASME 2012).

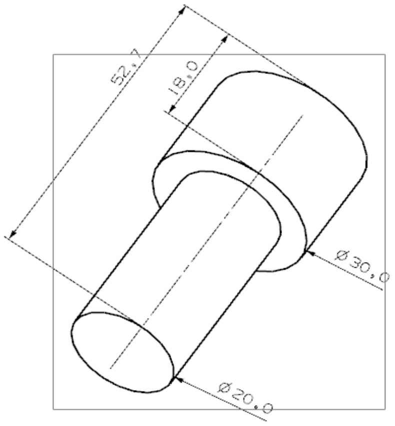

Figure 8. *3D wireframe presentation.*

3D dumb solids are created by manipulating real world three-dimensional objects. 3D dumb solids can be edited by adding or cutting from them, as if assembling or cutting in real life. Old programs that are supporting dumb 3D solids do not usually include tools to set limits to the motion of the components and programs do not identify interfaces between solids or components (LaCourse 1995).

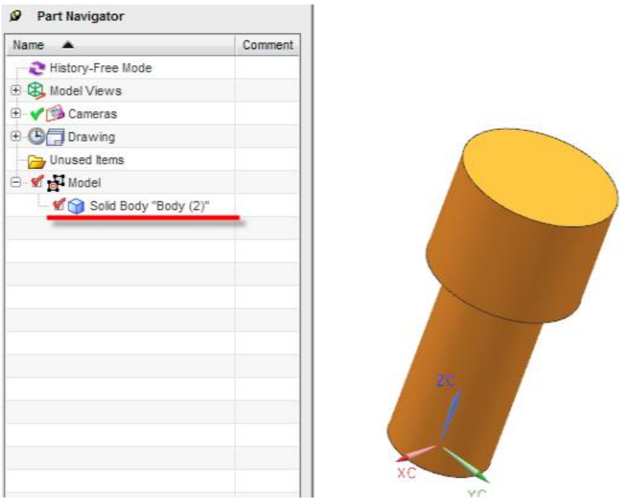

Figure 9. *Dumb solid model presentation.*

3D parametric solid modeling is based on parameters, which are adjustable. This capacity requires the operator to use tools that are controlling “design intent”. Design intent is normally in history tree of the model. History tree is the “program” behind the 3D model and the user is “programming” system to create model. Future modifications can be simple, difficult or even impossible depending how the original model was created. Users have to consider the consequences of the actions carefully when they are creating or modifying 3D models (LaCourse 1995).

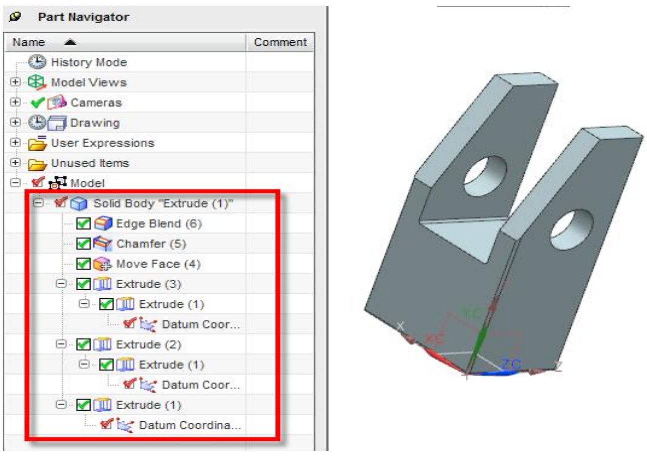

Figure 10. *Parametric 3D model presentation.*

Freeform surface modeling capabilities are offered in top end CAD systems. Models created with freeform tools can be more organic, aesthetics and ergonomic. Surface modeling combined with solids gives possibility to create products that fit the human form and still they interface with machines (Direct Dimensions 2012).

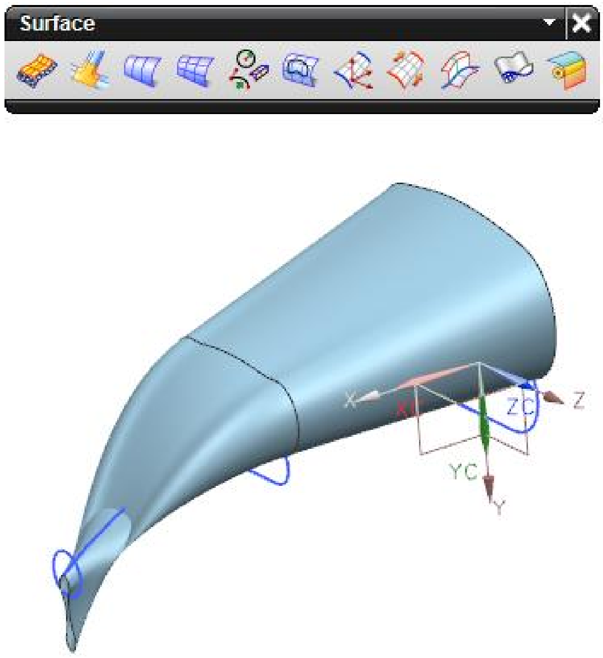

Figure 11. *3D freeform surface model.*

The latest big innovation in CAD is to combine parametric and non-parametric geometry editing. This capability removes in some cases the need to understand or undo the design intent history and models can be edited directly. Relationships between selected geometry can be created. Editing process takes less time and can be more innovative when designers have more freedom to edit geometry. Non history based system are called *Explicit or Direct Modelers*. In next chapters these tools are introduced and the influence to the CAD world is represented (PTC 2011).

2.3.2. Selecting a 3D CAD system

Companies are evaluating CAD programs in many different ways. Is there common thing in evaluating process that everyone should follow? Benchmarks can be still set but 3D CAD is becoming more of a commodity now. Today 3D CAD programs are quite similar with each other and it is hard to differentiate them. Big differences are in user interaction and interfaces. In some cases this can be selection criteria. It means that in these cases user preferences are significant. Selecting a CAD system that users prefer and they have already experience can save training cost. Today CAD is a basic tool for engineers and companies are looking for new employees with experience of a particular CAD system (Stephen & Wolfe 2010).

Upper management can also influence on a lot the decision when selecting CAD system. The influence can be based on experience from a previous company they worked for and successful implementation done there. Sometimes selection can be based on relationships between choosing and sales person. Unfortunately in these cases choose is not based on ability of the system to deliver business and process requirements or tools sets capabilities. Many times the status of the CAD provider is important. One big thing is company's stability but also presence of the company in the market plays some role. The best option or program does not always win. In many cases the cost is final factor for a decision.

Technical differences between CAD programs are still unknown and perhaps unimportant to many users. These differences can impact to processes in many ways. For example geometry accuracy of the CAD program can significant factor. Lower accuracy can offer smaller file size, faster system and more successfully feature creating. But on the other hand it can affect the leverage and use of the 3D data in the future. Too often these factors have too little impact in the selection process (Stephen & Wolfe 2010).

2.4. Parametric Modelling

Today most common CAD environment is parametric one. Parametric history-based CAD was introduced in the mid 1980s. Typically 3D models are created by extruding, revolving and sweeping 2D sketches. Sketches are locked into place with dimensions and constrains. New features are related to existing ones as references so model is a network of parent-child relationships (LaCourse 1995). "The parameters are similar to variables in a software program. Change the variables and replay the program to get different results."

Advantage of parametric modeling is that modifying can be done by typing in new dimension values for features. Parametric modeling can be very powerful with good skill in model creation. But there are also some weaknesses. Only features which are controlled with parameters can be easily modified. That's why it is important to understand the history of the model and features. Also when creating the model it is important to know at early stage which features will later require modification and which features can be constrained to other and they can only be modified when their parents change (Wong 2009).

3. INTRODUCTION TO DIRECT MODELING TOOLS AND HISTORY-FREE ENVIRONMENT

Direct modeling is used to describe many different things. In this work Direct Modeling refers to the ability of the CAD system to interact with faces, features, edges, parts and assemblies directly during the change or design process. “It means that the CAD system is intelligent, not necessarily the geometry”. CAD system with direct modeling ability can interact with geometry intelligently regardless where or how the geometry was created. Direct modeling tools should be able to recognize the information from the solid body and take advantage of it. In some cases direct modeling tools are better suited for simple geometry editing rather than full design process. Tools can be used when editing non-native CAD data or when history tree has got too complex.

Parametric history-based CAD has been leading mechanical design tool for many years now but because geometry is getting more and more complex with unwieldy network of constraints and dependencies, parametric CAD models have become hard to work with. Because of that CAD has become difficult to learn and lot of parametric information is lost every day. As a result CAD vendors are rapidly developing direct modeling tools. Direct modeling is easier to learn and with direct modeling tools lost of information can be reduced (Rudeck 2013).

Use of history-free environment or just use of direct modeling tools does not mean that design intent is lost. 3D features, constraints, parameters, driving and driven dimensions, tolerances and annotations can be added directly to 3D parts and assemblies. History-free means interacting directly with geometry rather than with recorded sketches and features in the history-tree. History-free environment doesn’t fit to every design process, but direct modeling tools can make modeling process in some cases much easier and faster (Rudeck 2013).

3.1. History

History-free modeling is called with many names. For example direct modeling, explicit modeling, dynamic modeling, Fusion Technology, Synchronous Technology or natural modeling all refers to history-free modeling. Technologies can have some differences but all those all are working directly with geometry. History-free modeling actually has been existed from the early days of 3D CAD. Early products were robust but also inflexible and slow. During that time computer technology was not supportive enough to create flexible systems (Rudeck 2013).

There are already hundreds of thousands of products designed successfully in history-free modeling environment. The number of companies using history-free technology for the whole design process is certainly smaller than number of companies using history-based, but designing wit help of direct modeling tools is growing rapidly. That's why CAD vendors are introducing and developing their direct modeling tools as fast as possible (Waters 2009).

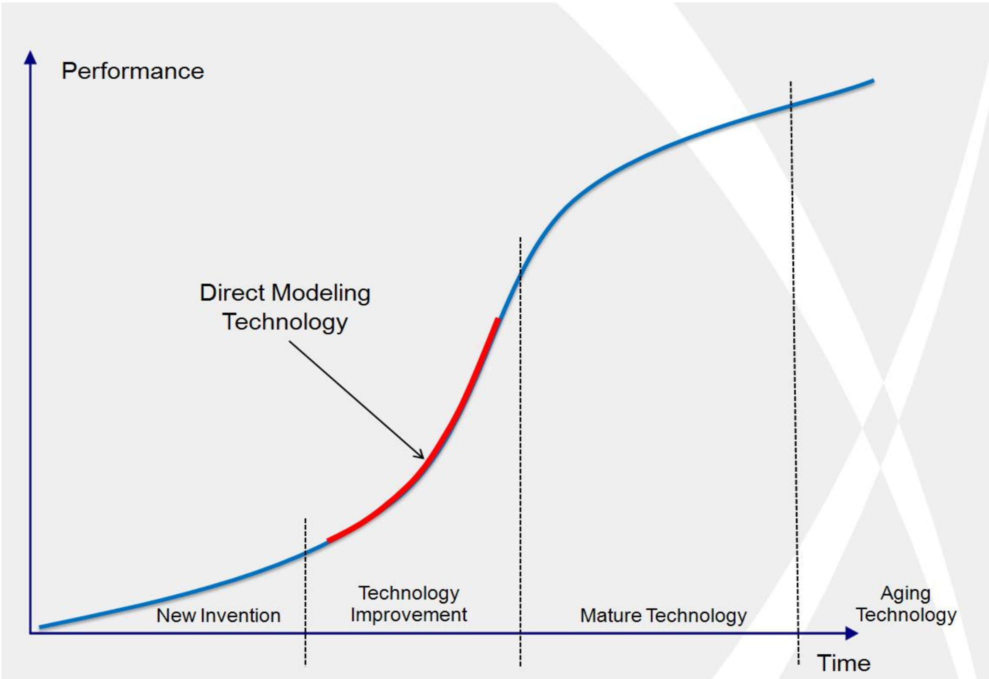

Figure 12. *Lifecycle of typical CAD technology. (Wujec 2011)*

3.2. Technologies

In this chapter most common direct modelling technologies are introduced. Key differentiators are presented but more detailed introduce is not necessary in this point, because details and capacities of technologies are changing rapidly. Later in the work there are more detailed look at influence to design process and capabilities of Synchronous Technology and Inventor Fusion.

3.2.1. Synchronous Technology

Synchronous technology is direct modeling technology from Siemens PLM Software. It is used in 2 different 3D CAD systems, NX and Solid Edge. Synchronous Technology combines two technologies (history-based/history-free) under the same user interface. This makes available the flexibility of direct modeling with the control and automation of traditional history-tree modeling. Technology scans and localizes the impact of edits to a model without lengthy regeneration times and inflexibility. When history-free environment in chosen the system informs that the history tree and all the intelligence in the tree will be lost (Rebrukh 2011).

3.2.2. Autodesk Inventor Fusion

Autodesk direct modeling tool is called Inventor Fusion Technology. Engineers need to switch mode every time direct changes are made to the models. Changes are automatically tracked in a single digital model. This is another hybrid approach which unites direct and parametric workflows. Fusion and its tools are more likely meant to maintain history tree, not to resolve problems that may show up in the tree. That's why lot of benefits of history-free modeling will never be realized (Schneider 2011).

3.2.3. SolidWorks Instant3D

SolidWorks has also presented own direct editing capabilities to its core history-based CAD tool. Tools called Instant3D is more dynamic parameter editor than direct modeling tool. With tool user can create and modify 3D geometry by selecting and dragging features and sections. Direct editing with Instant3D keeps the history tree intact which makes SolidWorks only history-based parametric CAD and most of the direct editing capabilities are not exploited but also disadvantages are avoided

3.2.4. CoCreate Modeling, SpaceClaim and KeyCreator

CoCreate Modeling is one of the oldest and more successful direct modeling technologies. Development has concentrated to easy-of-use and the ability to work with non-native and multi source CAD models. The strength of the software has been added parametric-like features, including the ability to constrain models and add assembly relationships at a geometry level in the history-free environment (PTC 2011).

SpaceClaim has built from the ground up to be a new type of direct modeler. Technology is said to excel at work in multi-CAD environment or when doing conceptual designing. Unrestricted editing and simultaneous dimensioning tools are allowed and minimal training is needed, but because of lack of traditional feature-based capabilities, products that require controls offered by parametric tools will have to support design process with complementary products.

KeyCreator is also software which has direct modeling tools as a mainstay. It has taken CAD interoperability as its primary target. Company has developed specially the selection and editing of design features in non-native solid CAD models. Direct Dimension-driven function gives parametric-like editing capabilities to user with any solid, regardless how or where it was constructed.

3.3. Tools

Models without history tree there are no any relationships or conditions built into the model that would drive modeling to any particular result. Command and command options are driving the results and users are choosing the command to use depending what results they want to have. With direct editing the results are depended on how the model was originally created like any other edit in history-based system. In history-free environment users are able to edit geometry and the result is instantaneous graphical feedback. Challenge is to find the right options to get different results. It depend on tools what kind of results are available and how changes are presented during editing.
To understand what is possible and how to get right results some practice is required as with any CAD tool. However results are often represented graphically while doing editing which makes understanding easier. Different systems have different way to get expected results and it doesn't mean when some changes are able in one CAD system same changes can be also done with another CAD. Direct modeling technologies have developed a lot since beginning and all the time there are more command options available. Good thing with direct modeling tools is that results are completely independent of how the geometry was originally created (Thckoo 2010).

When various faces are moved the result can be something else than is expected. This applies to history-free direct modeling and history-based direct editing. Results are depended tools and systems used. In figure 13 simply example of different modification options are presented.

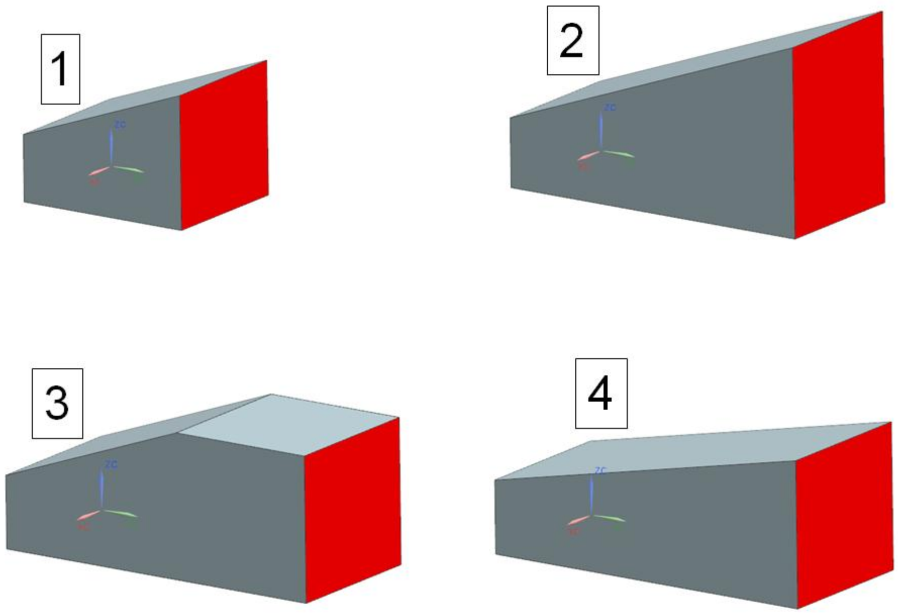

Figure 13. *Differences in topology editing*

In figure 13 part number 1 is original geometry that will be modified. Red colored face will be moved:

- In part 2 the face moved changes size and the adjacent faces are stretched. The angle of the top face is unchanged.
- In part 3 the face size is maintained and the angle of top is unchanged. Also new face is created so the topology is changed.
- In part 4 the face moved is maintained and the angle of the top face is changed. Topology is unchanged.

3.4. Key-Capabilities

In this chapter the key-capabilities of direct modeling are presented. Every software has its own capabilities and they can change a lot depending on the program, but there are some common reasons why direct modeling tools are gaining popularity

1. Technology
2. Interoperability
3. Flexibility
4. Lean

Computer power and technology has increased to level that makes history-free modeling a good alternative to history-based modeling. Graphically history-free modeling requires lot of power to present changes dynamically. Also complex changes in the topology require lot of computing power. Robust technology enables to capture design intent in geometry rather than through the modeling history (Kubotek 2010).

Direct modeling is ideally suited for Multi-CAD environment. In many cases imported models do not include modeling history and those can’t be controlled using parameters. There is no need to interrogate designs to understand how to make changes. This makes cooperation between team members more effective (Kubotek 2010).

With direct modeling tools models can be created and evolved faster. There are not so many limits to geometry creation process and methods so the CAD environment is much more flexible. Also reuse of data will be easier and more flexible. Users can focus on designing because modeling doesn’t take so much time and there is no need for pre-planning of future edits. Tools are much easier to learn and use (Waters 2009).

Even there is a lot more to a good CAD than editing geometry, but it is important capacity. The methods are fairly well defined in history-based CAD, but there are many limitations based on the fact that operations are maintained and ordered in the history tree. In history-based CAD features are either created or modified, but in history-free CAD and direct modeling tools the line between creation and editing is not so clear.

In some history-free systems even a sketcher is used very rarely. First geometry is put in place with sketch but after that geometry creation can be only mix of direct geometry manipulation and feature creation. Key capabilities of the history-free modeling is direct modeling tools, but also other methods to create different types of geometrical features, for example holes, bosses and pockets, are important (Ronge 2010).

3.5. Conditional and Feature Recognition

Different technologies for feature recognition have existed now around 20 years. Developers of parametric CAD have been trying to create techniques to turn dumb solid models into feature-based parametric models. In CAM programs feature recognition is used to automatically identify holes, pockets, bosses and slots in 3D geometry to automate the process of tool path generation. There are also many other uses for this technology in product design and manufacturing engineering.

In direct modeling and editing feature recognition is critical capacity. In direct modeling functions curves, faces or collection of faces has to be passed to the edit function. There are many ways to pick up faces to edit. The simplest way is to pick up one face at the time. Systems can allow use a viewport box select or conditional recognition such as tangent, adjacent and coincident. But most advanced technique is feature recognition and when it is working predictable it can greatly speed the direct modeling processes and make model behave more naturally predictably (Ronge 2010).

Feature recognition requires the user to select one seed face. After that feature recognition algorithm start to walk through the topology related to seed face to identify a collect of faces representing different features. Then, a set of constraints is created that preserves the feature shape or relationship during editing. If feature recognition is topology based it will work the same for any 3D geometry. The result may not be always same than expectations, but mature feature recognition technology should deliver predictable results. In history-free CAD environment the robust feature recognition is really important. Every modification is started by selecting the geometry that need to be changed. Because of that the process can be simplified with good conditional and feature recognition. Feature recognition tools are important to notice during evaluation process and in training.

Features that can be recognized:

- Boss
- Pocket
- Rib
- Slot

Relationships that can be recognized:

- Coplanar
- Coplanar axes
- Coaxial
- Tangent
- Offset
- Symmetric
- Equal radius

3.6. Direct Modeling and Freeform Surfaces

What are the capabilities of direct modeling technologies when freeform surfaces are developed and modified. Freeform surfaces are defined and created using B-Splines and NURBS. There are many freeform-surface modeling specialized modeling tools on the markets. Some of the systems do not create solids, but rather create and manipulate directly with the surface geometry. There are also many systems that combine surface modeling capabilities with volume solids and history tree. Technology is more complex when there are connectivity with solid and its history and surface. Connectivity must be maintained also during editing.

History-based modeling has simplified the problems with surfaces. Complex surfaces are created and modified by using sketches. In these case surface has own parameters in the history tree that can be modified. The system allows changing original sketches and regenerating the model to get results needed. It simplifies the problem, if the part is correctly created in the first place.

With history-free CAD surface design and manipulation can be more complex because there are no history trees. The system can offer a variety of different tools to create surfaces but when it comes time to edit surfaces there are no 2D sketches to go back. The manipulation has to be done directly with the surface geometry and the connectivity has to be maintained during the operation in predictable way. Good way to edit surfaces is to modify edges of the solid to get expected results. It is big challenge and there are still lots of to do but the development process of the tool continues. The newest versions of programs have advanced shaping toolkit that works with any geometry so it can be changed at any stage of the process (Rebrukh 2011).

For example NX now supports synchronous-enabled freeform design. User doesn't need to be expert of surface modeling because system has simple push and pull shaping techniques. Tools allow to create solid or surface, analytic or B-rep geometry. Organic forms can be inserted or modeled by moving constraint points, surface poles and handles. Geometry is also completely re-usable (Rebrukh 2011).

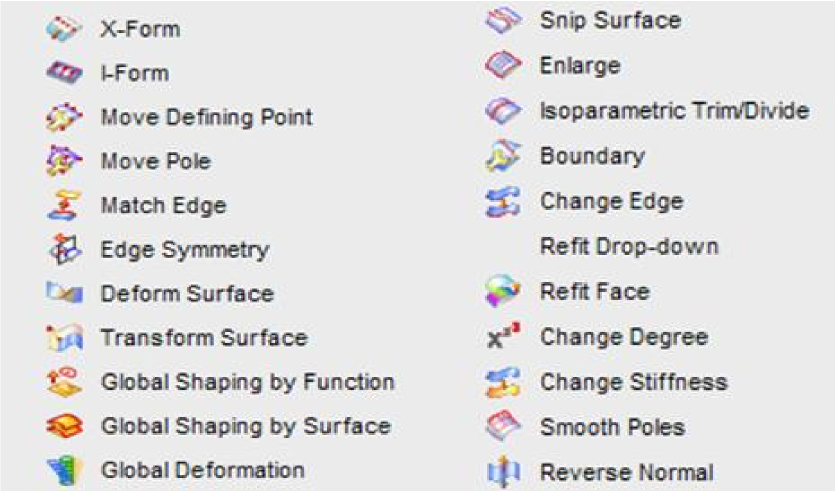

Figure 14. *NX7.5 Surface editing tools*

3.7. History-Free Parametric Modelling

In most of the cases the term "parametric modeling" refers to history-based CAD and history trees. But parametric modeling can also refer to the addition of persistent geometric relationships, constraints and parameters to 3D models. With this intelligence the behavior of a model can be controlled. The following list includes examples of intelligence that 3D geometry can include (Rebrukh 2011):

- Coplanar
- Coaxial
- Symmetric
- Offset
- Parallel
- Perpendicular
- Tangent
- Distance
- Angle
- Radius
- Diameter

Parameters in history-free environment are a bit more complex comparing to history-based environment. When in history-based CAD parameters are controlled in 2D space and based on sketches, in history-free they have to be controlled in 3D space. Because of these complexities the history-based platform may be the tool for fully constraining a 3D model. 3D parametric solvers are however developing a lot and new methods for creating relationships, constraints and parameters are created at every turn (Jackson 2012).

In history-free environment parameters can be defined anytime during or after model creation. Parameters can be added and removed when ever needed regardless of the completeness of the model. Also imported models can be fully constrained and parametrized with geometrical constraints and relationships. Here are two examples how geometry can be controlled.

<u>Example 1:</u>

In the first example a bushing model without history is controlled with dimensions. Dimension can controlled with functions and also they can be locked. At the first step the outer diameter is set. Then the values of inner diameter and width are referenced to the outer diameter. The inner diameter value is set to be 80 percent of the outer diameter value and the width is equal with the outer diameter. After that the model is geometrical fully constrained.

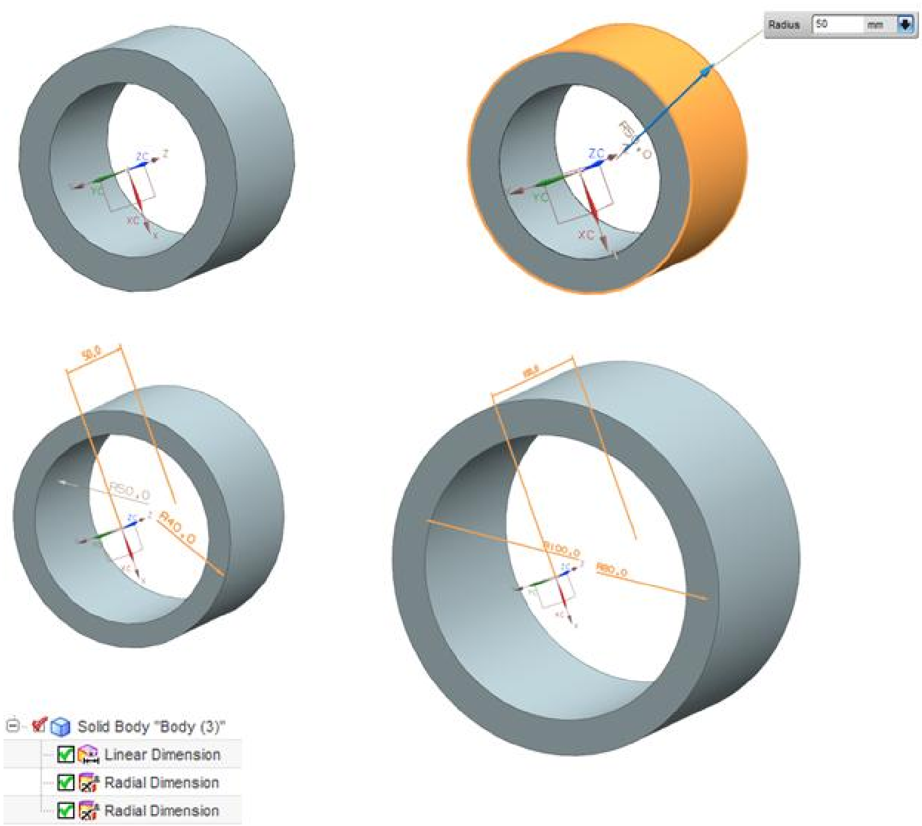

Figure 15. *History-free 3D parametrical control*

With these relationships models without history can be controlled simultaneously. With some systems it is possible to create multiple relation sets per part. However, only one relation set can be set as active at a time. This possibility gives a change to capture multiple scenarios or studies within one part.

Example 2:

Another simple case of a history-free parametric modeling shows how to create intelligent controls to a model. The model in the Figure 16 includes the geometry of the pocket and pattern that has been defined. In this case parameters are used to define number and placement of the pockets. When the parameter that defines the number of pockets is changed, the geometry is also adjusted. In this case the width of the base is changed and the change doesn't require any topology changes. User can also over constraint a part. In this case it depend on the system how over constraints are shown.

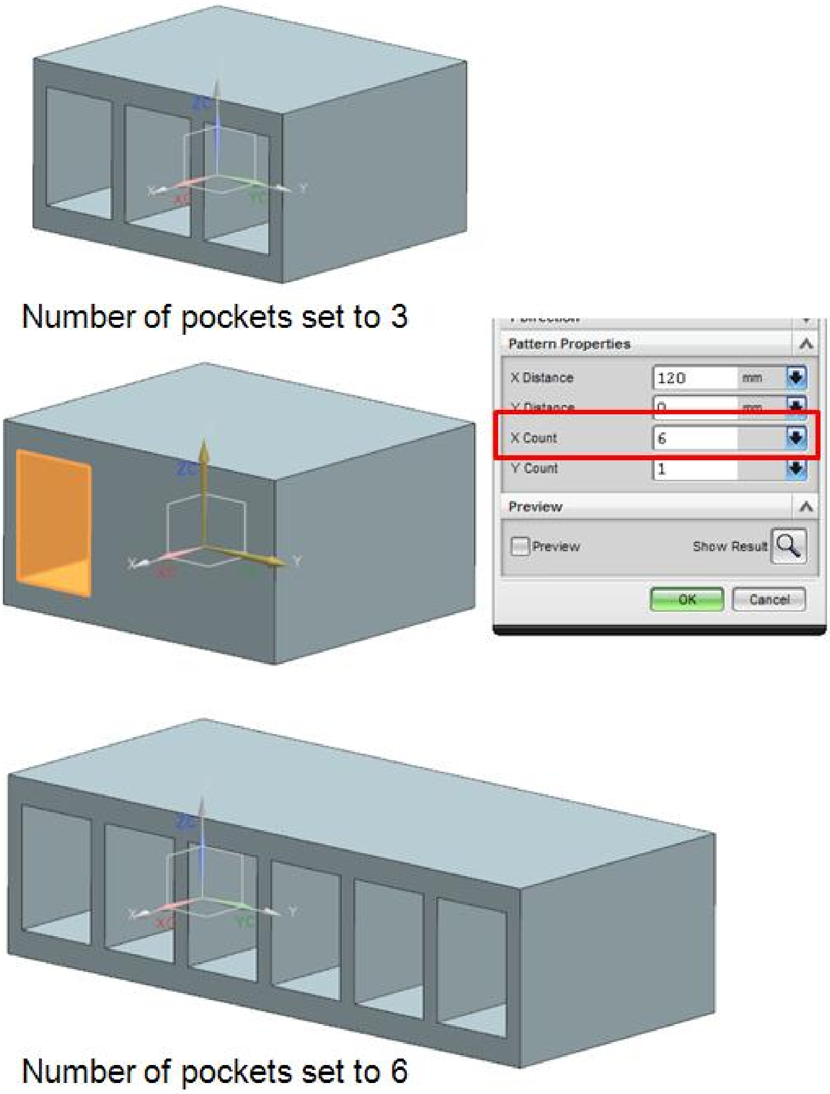

Figure 16. *History-free parametric intelligent*

Functionality of the parameters is only as good as the underlying geometry engine is at making other geometrical changes. As mentioned before, the critical areas are how the system is managing adjacent faces and topology changes. Parameter adding tool is only goof for to create a controllable model. But this is not always necessary. With direct modeling tools designers can focus on to the design task, and only use parameters when it is needed. It is not reasonable to waste time on creating data when it doesn't bring any value to the actual design.

3.8. Direct Editing and Dynamic Modifications

The term direct editing can refer to two different technologies. Both technologies are history-based. In first option modifications will result to new "direct edit" feature in the history tree. In second option, in SolidWorks Instant3D, changes are not recorded in the history tree, even there is one. The second one is also called dynamic modification.

Now a day almost all history-based CAD has some direct editing tools. With these tools users can directly manipulate geometry and the edit is recorded to history tree otherwise next time the model is regenerated, the edit will be lost. Direct editing is good option when quick changes to the complex model or imported geometry need to be done. In some cases history tree can be simpler and modeling process faster if the direct editing tools are used.

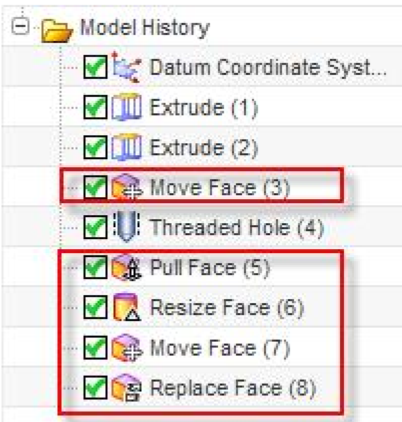

Figure 17. *Direct edits in history tree*

Dynamic modification tools, such SolidWorks Instant3D, are really different. There are no new records in the history tree, only the parameters of old features are edited dynamically. Parameters have to exist before modification can be done Method like this simply provides instant feedback of parameter edit. This may not always work depending how the model was created in the first place and it can also have impacts to child features.

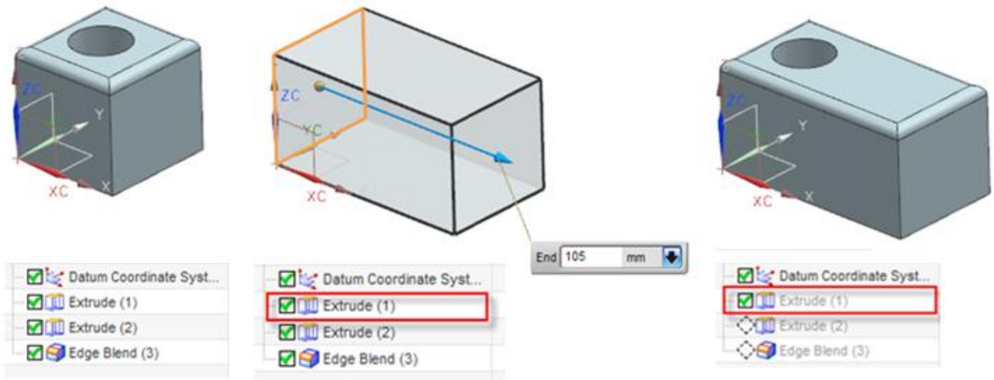

Figure 18. *Dynamic modification*

3.9. Explicit Modelling

Explicit modeling is common term for direct history-based geometry editing techniques. The best way to take a look to this technology is to compare it with actual history-free direct modeling. How is explicit modeling and direct modeling the same and more important, how are they different? Technologies can be compared in 3 areas: Geometry creation, geometry definition and geometry manipulation (Wong 2009). In the area of geometry creation explicit modeling and history-free direct modeling are the most similar. In explicit modeling these actions are used to create feature definition.

Explicit Modeling	Direct Modeling
Geometry features created based on sketches (like extrusions), derivated from existing geometry (like rounds) or freeform manipulations (pushing and pulling on surfaces).	*Geometry* created based on sketches (like extrusions), derivated from existing geometry (like rounds) or freeform manipulations (pushing and pulling on surfaces).

Figure 19. *Geometry creation. (Wong 2009)*

The real differences between the two modeling approaches are in the area of geometry definition. It means the way how the system is generating geometry and how it remembers how to do so. Explicit modeling is history-based and feature-based. Features are defined by parametrically driven dynamic building blocks. Those blocks are initially sequenced into history that presents the order in which model was created. With history geometry can be explicitly dimensionally lock down and repetitive modeling tasks can be automated. However functionality needs good knowledge of CAD software and best practices.

Explicit Modeling	Direct Modeling
Geometry recalculated from persisted *feature definition.* Geometry from features rebuilt in a *history based sequential order.*	*Geometry topology definition* persisted. Orginal actions or definitions to generate geometry not persisted

Figure 20. *Geometry definition. (Wong 2009)*

For making changes both modeling systems use very similar tools. Geometry can be modified by grabbing handles or geometry to push, pull or drag them. Changes are normally made in real time, so they can be previewed before finalizing. The real difference is how modifications effect on existing information in the model. In explicit modeling changes are made through existing feature definitions. For example extrusion cannot be changed to swept piece of geometry.

Explicit Modeling	Direct Modeling
Changes made through parametric, push/pull/drag and real-time modifications. Modifications made through *existing feature definitions*	Changes made through parametric, push/pull/drag and real-time modifications. Modifications made to *inferred sets of geometry*

Figure 21. *Geometry manipulation (Wong 2009)*

With explicit modeling models are changed through existing feature definitions and that's why it is not so flexible in terms of geometrical changes. Reasonable feature definitions and model history can enable good design automation but requires high CAD software knowledge and best practices (Jackson 2011).

3.10. Direct Modeling and Variant Design

In the past there were several advantages of history-based modeling and ordered model compared to history-free. One of those was management and development of part family or variant parts. History tree offered good possibilities to change parameters and create variant designs. It was relatively easy to create and represent a part in different configurations or states. Modeling standards and careful development made possible to "program" model to support the product variants only by changing parameters. But this was only working if the history tree of the model was "programmed" right way to support this actions.

With direct modeling tools it doesn't matter when, where or how the geometry was created as long as it is right. For example models provided by supplier are normally without history and parameters. With direct modeling tools it is easy to simplify geometry and use it when needed. Model rebuild is not required anymore to do that. Variant designing can be done without strict modeling practices, proprietary data form, model rebuilds and huge web of references and relationships. Also planning ahead the history tree is not required so designers can focus on more functionality and possibilities of the product (PTC 2011).

3.11. What to Look for in a Direct Modeller

Direct modeling tools should offer a wide range of flexible geometry creation and editing tools. Users should be able to push, pull or rotate geometry and have expected and intelligent respond. Also is important, that users can modify geometry also by typing dimensions. This static mode requires much less computing and display resources so it helps modification in very large models.

Most advanced direct modeling systems are providing good variety of options in creating 3D geometry. This includes tools for creating geometric relationships, constraints and parameters as well as full free-form surfacing. Direct modeling CAD can combine freedom of designing with traditional mechanical design and manufacturing tools. Some of the systems provide to take advantage of solids, surfaces, wireframes and even drawings to create organic shapes without the need of extensive training. Four primary areas in direct geometry manipulation are geometry selection, transform definition, predictable results and design intent. These areas must be considered when looking at capacities of systems. Direct modeling system has to provide intuitive methods to get wanted results (Waters 2009).

3.11.1. Geometry Selection

Direct modeling system has to provide intuitive methods for selection of geometry and automatic selection of geometry depending geometrical characteristics. Geometry edits involve almost always a face or a group of faces that are modified. Possible methods for selecting faces can be for example (Rebrukh 2011):

- Single
- Multi-select
- All
- Feature
- Region
- Pocket/Boss
- Rib
- Slot
- Adjacent
- Tangent
- Chain/Connected
- Viewport box
- 3D box
- By color

3.11.2. Transformation Definition

After selecting geometry that will be edited, the change has to be defined. It means that collections of faces are positioned in 3D space. Direct modeler should have good variety of methods to do this change. CAD programs are helping the process to define 3D transformations in many different ways. They can include icon that includes 3D direction vectors and 3D axis. Existing geometry and coordinate systems can be also used to specify dimensions, points, vector and axis. The best option is to include all this methods. Here are some options to define transformation (Rebrukh 2011):

- 3D direction and distance
- 3D axis and angle
- Point to point
- Distance between points
- Radial
- Mate
- Align
- Match points (3 points to 3 points)
- Dimension (linear, angle, references, formulas and functions)

3.11.3. Predictable Results

Direct modeling technology is basically moving selected geometry. After defining transform the CAD system provides results. In most of the cases results are expected but not always. When pulling and pushing on faces there are normally many solutions that can be derived. Results depend on system and options used. CAD should not be only a geometry making machine. It should indentify conditions that are important to mechanical design.

This area can be divided to two different parts. First one is adjacent faces. It is critical what will happen to the adjacent face when a face, or collection of faces, is moved. Direct changes to geometry usually require adjacent faces to be adjusted in some way and it should happen predictable way. In the example below shows three different cases where the direct modeling tool has to make adjacent faces adjust. The model is without history-tree, so features cannot be used. In all three cases the changes are simply and no change to the topology of the model is required (Rebrukh 2011).

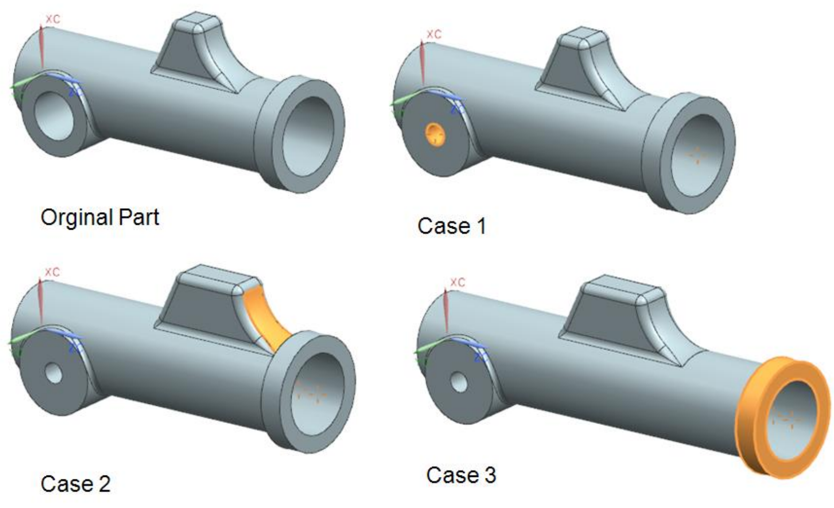

Figure 22. *Adjacent faces*

In the first case simply diameter change of a hole is presented. In this case there is only one adjacent face that has to adapt. In the case number two the modification effect on multiple faces. Changes get more challenging when the adjacent faces are blends. It depends on system if faces are recognized as blends. In some history-free systems are attaching an attribute to a blend face so that the system knows it is a blend. In the last case a collection of faces are selected and moved. These three examples are very simply and systems need to be tested in more typical situations that might be found from modeling process.

When the faces are pulled and dragged there is a high possibility that topology of the geometry is changed. In the modeling world "topology" describes how a b-rep solid model is connected by points, edges and faces. It is critical how the system handles topology changes. How the system represents when a face or faces are forced to run into other faces. The moving tool can have many different options, not only to define motion and distance, but also to define overflow options. In the figure XX some examples of topology changes are represented. Simple hole, pocket and rib are moved from face to another to show the result. Transformation can be defined different ways to get a different result.

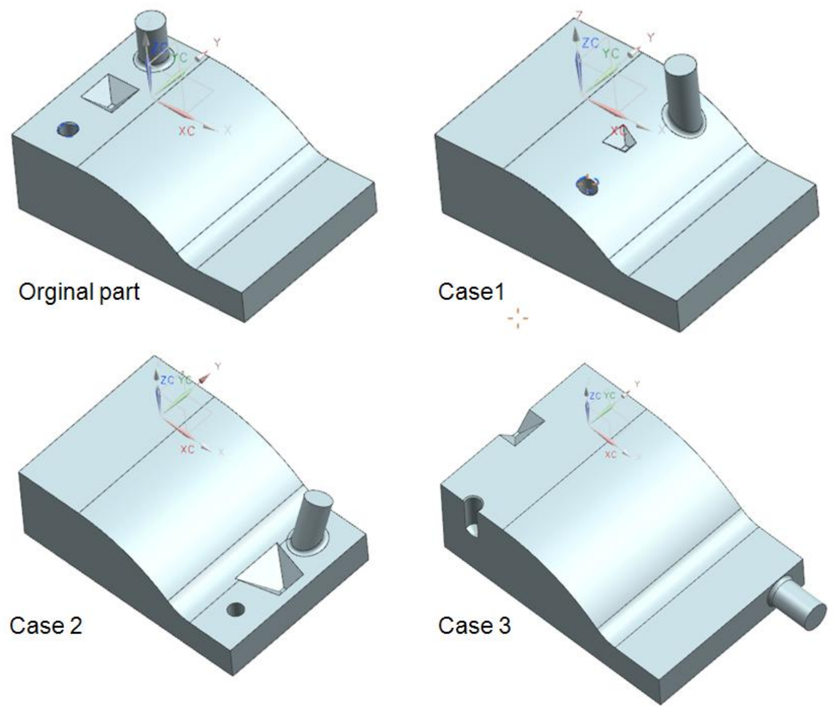

Figure 23. *Topology changes*

The first case shows a direction and distance transformation. Topology is only changed a little. In the second case a dynamical direction, distance and rotation changes has been made. Now there are more topological changes and also some new faces appear. The last example shows point-to-point motion with rotation. Results of each and how the topology has changed can be seen.

3.11.4. Design Intent

When looking at direct modeling tools is how the design intent can be added at the geometry level. To create design intent there are several types of relationships that can be captured. In this case the design intent refers to geometrical features, not to assembly relationships. Here are some examples (Rebrukh 2011).

Dimensions:

- Angular
- Distance
- Radial

Relationships:

- Tangent
- Coplanar
- Coaxial
- Perpendicular
- Symmetric
- Parallel
- Fixed
- Offset

In some systems you can also look for and show related faces.

The capabilities to add information into the model is the thing that should be noticed. in some systems it may be automatic and in some system there is flexibility to control these conditions during modification. In this case it is easy to look at how modifications work when conditions are on because graphical is available.

3.11.5. Special Characteristics

Tools and use of them can also have some special characteristics what needs to be taken into account. These characteristics are related to design process and the use of the tool. Complexity of the tool and general training requirements are important to consider when evaluating tool. It is good to check how hard the tool is to learn and is the modeling after implementation any faster and more intuitive. User interface can have a big impact to usability of the tool. The need for modeling standards and best practices are related to training requirements (Ronge 2010).

The need to plan ahead before modeling is normally time consuming with parametric tools. How this thing changes when using direct modeling tool. Do users need to think how to create geometry that they can change it also in the future? If the answer is yes, it might be that the tool doesn't bring any flexibility to design process. Also capability to reuse history trees and resolve history tree conflicts are important characteristics related to flexibility (Ronge 2010).

One important characteristic is the capabilities to work with other CAD forms. How robust this interoperability and data exchange is, will depended on many things. Geometry is common between CAD systems, but the possibilities to work with this geometry fluctuated between systems.

4. HISTORY-FREE VS HISTORY-BASED MODELING

Now a day most of the CAD users are really familiar with history-based CAD. That is because most of them haven't seen any other ways to do modeling and history based CAD is only thing they have ever used. But the big question is with CAD is; do the CAD users spend more time designing or modeling. In history-based CAD modeling process is like "programming the 3D model". User has to understand what the rows in history-tree means, how the model is structured and how does the change effect on to the 3D model. Sometimes understanding these model functionalities is needed but in many cases it is also unnecessary information. Only few people are familiar with history-free CAD environment. They may have some experience of direct editing and functionality of the tools. So what's the real difference between these two environments?
In history-based CAD users are creating history trees by using 2D sketches, modeling features and specific methods to create relationships and structures. 3D geometry is created when CAD runs all information tracked in the history tree. Also the changes are not done by modifying 3D geometry but, rather modifying the program that creates then different results. In history-based CAD the history tree is the master. Because of this users have to be cautious and they need proper training when creating or manipulating the history tree (PTC 2011).

History-free CAD and direct modeling has gained certainly more attention during couple of last years. Many CAD users are now having the first experience of it. The experience can be good or bad depending on many different factors. History-free direct modeling is fundamentally different that working with a history tree. To understand the full advantage of history-free modeling requires thinking outside the familiar history-based box.

History-free modeling process may not be structured and that can cause some problems if a product development process demands it. A model made with structured modeling process is usually structured. A Structured model can provide flexibility and inflexibility where needed. But structured models are not always needed and structured models can be also created with history-free CAD. It is important to understand the value of structured modeling process to product development process. If there is no extra value from that it may be reasonable to think direct modeling and history-free CAD as an option. Mistakes can be made in both technologies and in every case the models have to be validated. In the next chapters different ways to create and edit geometry and differences between technologies are represented.

4.1. Editing 3D Geometry

As mentioned before the 3D geometry editing is the thing what makes the CAD systems different when using 3D environment. History-based systems try to add tools to interact directly or more explicit with geometry and history-free systems are creating tools to drive geometry parametrically. 3D CAD tool is basically made for describing and transforming 3D geometry in virtual environment. This can be done directly or indirectly whether the system is history-based or history-free (Figure 24).

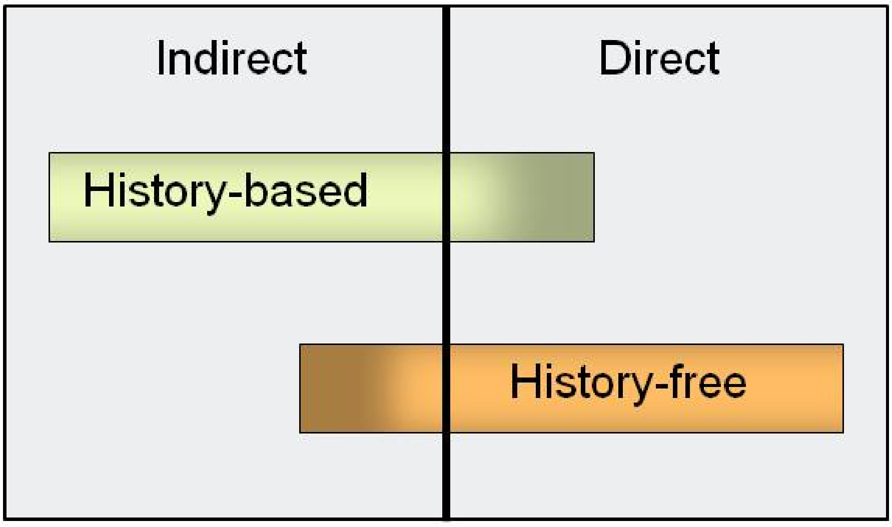

Figure 24. *3D geometry editing. (PTC 2011)*

As shown above, there are four different areas in 3D geometry editing:

- History-based indirect editing (traditional)
- History-free indirect editing
- History-based direct editing (explicit)
- History-free direct editing

It is important to understand advantages and disadvantages of these areas to find right tools for right modeling and product de tasks. In most of the cases the 3D CAD system can provide tools for editing geometry using two or more of these methods. On the other hand sometimes form of 3D data forces to use some particular tool or remodeling is required (Wong 2009).

4.1.1. Editing Geometry - Indirect Editing

Indirect editing is typically in history-based parametric modeling but can be also used to create parameters to history-free models. Parameters, dimensions and other intelligence are associated to 3D model and the transformations and relationships of the model can be defined by using those. In history-based system the intelligence is added during the modeling process and is captured in the history tree. In contrast, intelligence in the history-free model is tracked in the B-rep model and can be modified anytime. With indirect editing user defines by adding intelligence what will change, and how it will happen.

Editing is done through this intelligence and it defines the 3D geometry. The geometry is actually completely dependent on the intelligence and how it is setup and structured. The benefit of this technology is that behavior of the model can be captured. This is useful thing if the future changes of the model are predictable or anticipate and it is important to tightly control relationships between model details (Wong 2009).

4.1.2. History-Based Indirect Editing

The most familiar 3D CAD environment is indirect history-based one. 3D geometry is managed with parameters in the history tree which includes structured parent-child relationship network. This structure has to properly organized and managed and it is something that every history-based CAD user has to learn to be proficient with tool.

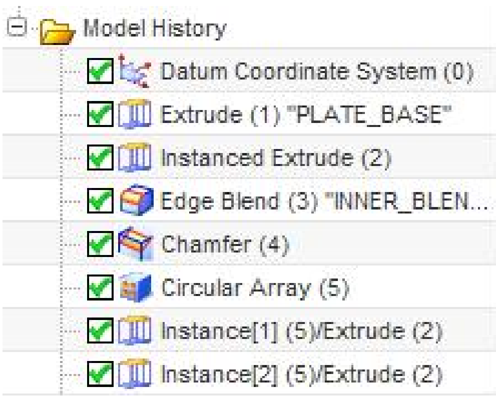

Figure 25. *Parametric history tree*

The modeling and editing is done through the history and the history tree is regenerated and solved linearly after editing. When working with history tree it is important to understand the structure and how the change of the tree will impact to other features. With the indirect editing capabilities it is possible to make an edit that invalidate the model (LaCourse 1995).

In the chapter 3.8 dynamic or instant modeling tools are introduced. This capability makes possible to interact directly with intelligence of the model but intelligence is still solved linearly. It can look something like direct modeling, but it is still indirect editing and the results are completely depending on the structure of the parameters.

4.1.3. History-Free Indirect Editing

More unfamiliar technology to CAD users is history-free indirect editing. Technology provides the possibility to interact indirectly with 3D B-Rep geometry using parameters. Technology is represented in chapter 3.7. The parameters are not captured to the history tree, but are rather tagged directly to the faces, points and edges of the B-Rep model. Then relationships between parameters are solved synchronously or nonlinear. The order, in which parameters were set, doesn't have influence.

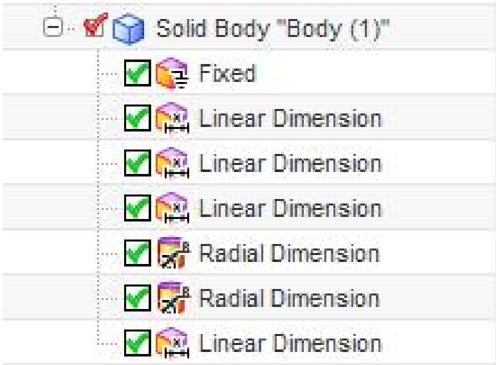

Figure 26. *History-free inderct editing*

In this case the geometry is being modified rather that recreated. When modifications are done indirectly to B-Rep model, the resulting tranformations must not brake the B-Rep geometry and results should be reliable and expected. After creating the parameters that controls geometry, is important to understand this network that not wanted modifications are not done. Graphical feedback and good performance of existing relationships is important in this case (Thckoo 2010).

4.1.4. Editing Geometry - Direct Editing

When working with direct editing environment there are no such intelligence to manage or assign as in indirect environment. The technology provides intelligence with the B-Rep model itself. Direct manipulating tools are not mature as history-based parametric modeling tools but tools are getting much smarter. The edit can be done directly by selecting and defining the transform. Direct editing tools are available in most of the history-based CAD systems and of course in every history-free ones (Jackson 2014), (Thckoo 2010).

As mentioned before, direct modeling tools effect directly to the B-Rep geometry, so intelligence or "program" behind the 3D geometry is not needed. Users need to define "what" (the geometry) will be modified and "how" (the transformation) the modification is done. The different systems have different tools for these selections but the process is very similar.

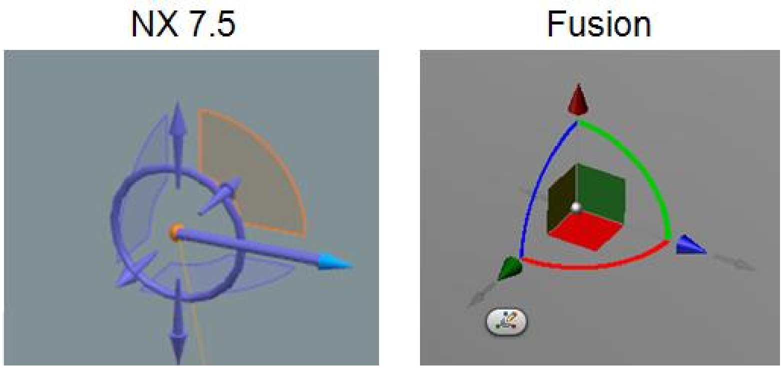

Figure 27. *Direct transformation tools in NX and Fusion*

After defining the direction or axis, the distance and angle must be set. Systems have different methods for that but typically user can drag a distance or angle or type in a number. Some systems let users also to use the reference geometry from other parts to define transformation.

4.1.5. History-Based Direct Editing

History-based direct editing is fairly new technology in the CAD world. With this toolset users can act directly with B-Rep geometry but history tree still remains. Every edit is captured to the tree and each direct edit must be reapplied when making indirect changes. History tree must be restructured and maintained during modeling like when using parametric features. Direct edits can impact parent features and will impact child features. When using direct edits the history tree can get really complex. Because of that, direct edits should be avoided until late modeling steps.

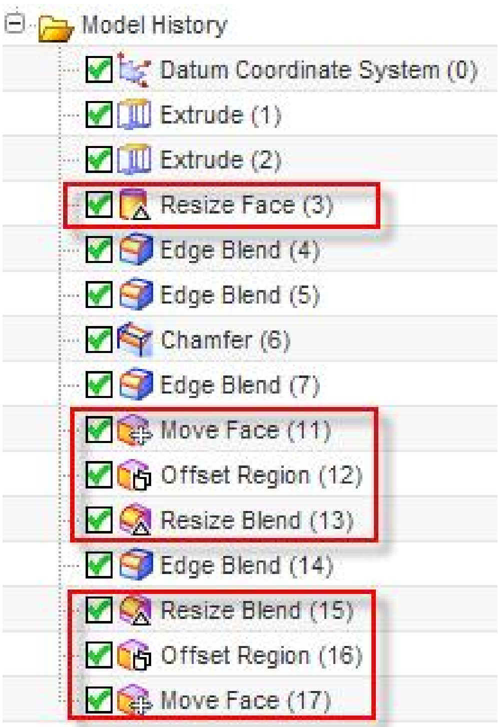

Figure 28. *Direct edits in history tree*

In history-based system it is easier to select features, if there are already defined ones in the history tree. Geometrical instances can be read as a feature or as a face. The weakness of the technology is that changes to B-Rep topology are not so flexible than in the history-free system. Also editing multiple solid bodies can be more challenging than in the history-free system. However the direct editing tools in history-based system are nice capability when working with imported models (Wong 2009).

4.1.6. History-Free Direct Editing

For many CAD users history-free modeling means that design intent is not captured. This depends how the design intent need to be captured. Direct modeling tools offer many ways to create and edit intent of designing. It can be different than parametric capturing, but still the intent is in the 3D geometry. With history-free direct editing tools the geometric problems are not driven through the parameters. Direct modeling is default tool in history-free environment. When there is no history tree, the edit is a one-time event and is not recorded.

To make history-free modeling powerful direct modeling tools are needed. The tools are similar with the history-based direct editing tools, but there are no limits caused by parent/child relationships. Intelligence use of information in the B-Rep geometry is critical for history-free direct editing tools (Jackson 2014).

4.1.7. Parametric-based Modeling and Direct Modeling Differences

The biggest difference between these two modeling techniques can be found from the area of geometry modification. Indirect and direct tools can be found from both of the CAD environments, history-based and history-free. In the figure xx the characteristics of indirect and direct modeling tools for both of the CAD environments are represented. In the figure xx the difference of technologies in geometry creation and modeling area is represented (PTC. 2011.)

	Indirect	Direct
History-based	-Basic method to create and modify geometry - Tools are really advanced and mature - Rules and best practices need to be strict -Final model has lot of relationhips and rules	- Faster and more visual technology to edit parametric-based geometry - Relationships and modeling rules still exist - Changes can be tracked from the history tree - Tools are developing
History-free	- Tools for creating parameters to 3D models without history tree - Functionalities and limitations can be set to the model - Technology is young and needs powerful direct modeling tools to work	- Method to modify geometry - Tools are developing - Modeling is intuitive and free - Interoperate with multiple CAD data form is much easier - Geometrical changes easier/faster to do

Figure 29. *Modeling technique matrix*

Parametric-based Modeling (Indirect)	Direct Modeling
Geometric features created based on sketches (like extrusion), derivaded from exsisnting geometry (like blends) of freeform manipulations (pushing and pulling on surfaces). Geometry recalculated from persisted *feature definitions*. Geometry from features rebuilt in a *history based sequential order*.	*Geometry* created based on sketches (like extrusion), derivaded from exsisnting geometry (like blends) of freeform manipulations (pushing and pulling on surfaces). *Geometric topology definitions* persisted. Orginal actions or definitions to generate geometry not persisted.
Tools:	
Parametric: Stepwise geometry creation or changes made through *explicit modifications to dimensions or variables*.	**Push, pull or drag:** Real time geometry creation or changes made by *push/pull/drag interaction* with geometry, handles, etc.
Feature-based: Modifications made through *existing feature definitions*. Changes propagate to other related or depent features when necessary.	**Direct:** Modifications made to *directly selected and/or inferred sets of geometry.* Selected or inferred set of geometry is *manipulated with actions.*

Figure 30. *Indirect and direct modeling*

When comparing history-based parametric modeling and history-free modeling it is important to consider how they may or may not support the requirements. The idea behind these two technologies is slightly different and that's why comparison can be challenging. Because the awareness of history-free modeling increases, there seems to be a growing desire to merge the benefits and problems of these two technologies. So what are the benefits and problems of both technologies?

4.2. Benefits of History-based Modelling

A CAD system is either history-based or history-free, it cannot be both. When the history tree is gone, it cannot be brought back without starting over. When there are history tree the constraints and relationships can be easier to maintain. This is not always, but at least in history-based system the model is based on these relationships and parameters between features. So basically the benefits of history-based systems are related to the well ordered history tree with its parent/child relationships. This is why history-based system is not depended on direct modeling capability, but history-free system doesn't exists without it. For a history-based system it is nice to have this tool, for example when working with imported or migrated data.

The benefits of the well ordered history-tree are typically related to controllability of the model. What more detailed benefits this area includes? The parametrical controlling is normally easier and more intuitive through parent/child relationships. This supports better part families and configure-to-order actions. If history-based tools are compared to history-free tools, maybe biggest difference is the "shell" tool. This feature has normally intelligence relationship with parent feature. Wall thickness and open faces can be set and modified in history-based easier than in history-free (PTC 2011).

Second benefit is availability for multiple states i.e. machined parts. When geometry is changed at first stage i.e. casting part, the modification can be automatized to lower level i.e. rough machined and machined. Features can be suppressed and added to other states and still the relationships to the original state can exist. Also controllability of freeform surfaces and shapes in a solid model is more mature in history-based. Complex blends can be problematic to manage in history-free systems. Well structured parent/child relationship brings advantages to surface editing in a solid model that is hard to beat. Without relationships and sketches it is hard to regenerate complex surfaces. If the features are ordered dependent, it can be easier to manage vertex regions related to blends or other features. In history-based system this order can be reordered to get different kind of vertex region (PTC 2011).

The list of the history-based technology benefits:

- History-based system can be still more familiar with most of the users. It is still the technology what is taught in schools.
- History tree captures automatically design intent.
- History tree allows for faces to be consumed by an edit. These faces can be exposed based on another edit.
- Modeling process and behavior is specific.
- Good for processes that need structured engineering data and effective configuration tools
- Technology is very mature with large scale of functionalities.

4.3. Benefits of History-free Modelling

To realize all the benefits of the history-free environment, the system should have some characteristics. Some of the advantages can exist also without these characteristics, but then there is need for some extra functions which can make use of the system even heavier. At first there should be no need for up-front planning in the process. Sketching should be flexible and sketches should not have any impact to the future use of the model. The tools to create and modify geometry should be mature and there should be variety of methods to work with geometry. In-context and top-down designing should be normal work methods and line between part and assembly mode should be flexible. Tools to add design intent where needed should exist.

The key advantage of direct modeling is that it provides environment to modify geometry more intuitive way. Users can start from the simple shapes to create complex parts and assemblies. Direct modeling enables to create and modify elements of the design, not only the portion of unconstrained shapes. Design features are easier to reuse and duplicate if needed. Because of simplicity and intuitiveness of the tool, users can get up and start to do actual designing through modeling in much less time compared to parametric CAD. This makes possible use of CAD tools also for users who are not normally spending the time with modeling. Normally these upstream and downstream users can use modeling tools to create and edit geometry for their own needs (Waters 2009).

Direct modeling has some major advantages to FEM and manufacturing engineers. Manufacturing normally doesn’t use parametrical models because of the complexity and lack of interoperability. With direct modeling, manufacturing engineers can import the geometry regardless how it was produces and do the changes needed for manufacturing process. This makes communication between designing and manufacturing more intuitive. In the area of FEM, the analyst can easily modify the model to make changes required for analysis such as removing features and combining surfaces. Prepping the model for analysis is much less time-consuming with direct modeling tools. Also interoperability is one of the biggest advantages of the direct modeling. The solid geometry can be edited with the tools regardless the original form and creation tool (Waters 2009).

Direct modeling tools and history-free environment can be suitable, if design/product development environment has these characteristics:

- Need for quickly review multiple concepts.
- There are a lot of people working in product development who are not CAD experts.
- Environment includes lot of different data formats and multiple CAD tools.
- product lifecycle is short and there are no need to add functionalities to CAD models
- Assemblies are large (10.000+ parts).
- Need to leverage, share and reuse design data between multiple CAD formats, it is easier to do so with 3D models rather than programs.

It is important to remember, that history-free CAD is not for everyone. Direct modeling tools are not the only ones what is needed in product development toolbox. History-free environment doesn't have answer to all the challenges in today's CAD world. But it can offer some major advantages to the part of the product development process, not only the modeling advantages. Advantages are depended on how the toolset is implemented within CAD system.

The list of the history-free environment and direct modeling technology benefits (Waters 2009):

- Direct modeling toolbox can offer help to missing functionalities
- IP management also in the geometry level
- Robust Multi-CAD environment, value can be extracted from any geometry created by any CAD tool
- Robust collaboration and teamwork between team members, suppliers and partners
- Product development process can be improved by shortening time-to-market, creating easier multiple concepts with many iterations and decreasing the product development cost of low volume products.
- File size is smaller if the model doesn't include history tree
- Tools are easy to use
- More natural in-context, top-down, bottom-up design (flexibility).“What you see is what you get”
- Avoid of re-computing/regeneration issues

4.4. Problems of History-Based Parametric Modelling

Most of the problems with parametric CAD are from the same area than advantages of the history-free modeling. In the first place direct modeling tools were developed to help with missing features in the history-based parametric modeling. History-based modeling has now existed couple of decades and there has been only few options to replace this modeling method. That's why problems have been known for long, but users have thought that problems are just characteristics of the modeling process and they just have to live with that.

The problems in the process exist from the beginning. If user doesn't plan a model wisely or unforeseen changes are required, the history may prevent the model from being changed in the manner required. This can cause lot of rework and unnecessary modification actions. Normally the model just gets more complex and the future changes have more possibilities to fail. Also keeping the track of relationships and feature dependencies gets harder. In some cases the model can fall apart because of the complexity (Jackson 2012).

The parametric modeling process requires normally a high level of expertise and several weeks of training before user can use tools proficient way. The complexity usually means that use of parametrical CAD is normally limited to engineers who are using the system daily. The geometry needs to be exported to different and simpler environment if there is need to use it to other than designing task. This breaks the natural link between the design and manufacturing geometry and increases the risk of errors. Typically there is lack of interoperability between different history-based CADs. History-based systems have own specific methods of building the 3D geometry based on instances in the history tree that is incompatible with others. After importing data from another system, users often need to rebuild models from scratch to re-establish parameterics constraints. Also concept modeling with engineers who are not involved to CAD can be challenging and time consuming. The changes are hard or impossible to execute because of the architecture of the history-based CAD (Jackson 2012).

With reasonable best practices and fulfilled requirements history-based can be powerful tool. The requirements are similar with basic software development (Mantyla, Nau & Shah 1996):

- Need of clear understanding of the target or intent before starting
- Creation of clear structure that others can understand
- Structure has to support the intent
- Close attention to relationships and references
- Well organized components that are in enough small entities
- The need for modeling standards and best practices

This list leads to challenges that are history-based modeling:

- Debugging the history tree
- Reusing history trees
- Managing very large and complex models
- Managing large amount of relationships
- Collaboration between history trees
- Complexity of the tool and general training requirements

4.5. Problems of History-Free Modelling

Because the CAD world has used to history-based working methods, history-free technology has lot of to prove before breakthrough. Most of the engineering processes and methods are based on parametrical history-trees and tracking the information from it. History-based CAD is still the way of working that is taught in schools, and most of the

engineers think that it is the “real” CAD modelling technique. Because of the strong know-how of old method, users might have some resistance to admit new working methods. Of course this is not the problem of technology, but still it can be counted as a challenge for history-free CAD (Rudeck 2013).
Problems and advantages are highly depended on product and process requirements. As mentioned before, different technologies and working methods are suitable for different design environments. If history-free environment is chosen laying on wrong facts, it can cause lot of extra work and lost of model intent. Also some application using parameter or parametrical information from the CAD system may not work expected way or at all (Rudeck 2013).

History-free environment doesn’t exist without direct modelling tools. These tools can be intuitive and easy to use, but there is also other side of this thing. When history-free environment is chosen there will not be history in any cases. If there is suddenly real need to create parametrical history tree with relationships, it is not possible by using history-free modelling environment and direct modelling tools. Direct modelling tools can also cause some modelling errors. Typical CAD users are not as familiar with direct modelling tools as they are with history-based tools. Direct changes can be sometimes hard to notice, because direct changes can force related geometry to adapt unexpected way. When there is no history-tree, the other designer than original modeller of the part can misunderstand the idea behind the model. This can cause changes which breaks the original design idea of the part (PTC 2011).

The list of challenges in history-free system

- If the model is once with out history, there will never be history without rework.
- Technology is still pretty unfamiliar with most of the users and different than traditional CAD technology.
- Methods of working have to change if the environment is changed.
- In some cases lack of design intent information
- Different CAD software have different tools for direct modelling – There are no similarity like in history-based tools
- Possibility to modelling errors that are hard to notice
- History-based and direct modelling tools in the same user interface can result to complex CAD tool.

5. ASSEMBLIES AND DIRECT MODELING

In product design and development process designers have to consider functionality and ease of manufacture of individual parts and components. Also attention has to be paid how to assemble the parts. These aspects of design have been too often left with too little attention, which can cause problems in manufacturing. Assembly-related problems that are discovered on the shop floor are typically much more expensive or impossible to fix. Assembly modelers who facilitate the creation, modifications and analysis of complex assemblies are in the critical role in the assembly design process.

Design and analysis of the assemblies are critical stages in product development. It has been estimated that a half of manufacturing costs are related to assembly process. The assembly design stage has the greatest potential for increased productivity and decreased production costs. Designers typically pay attention to functionality and manufacturing but easy of assembly process can be hard to outline specially without good 3D information. In many cases different persons are planning the functionality and assembly processes (engineering and productization). Design for assembly can be in some cases a key element in successful product development (Ronge 2010).

According to DFA techniques, the procedures below can help optimize assembly design:

- Calculation for weight, center of gravity and moments of inertia
- Analysis of the motions of mechanisms (Kinematic)
- Analysis of the motions of mechanism and the effects of mass (Dynamic)
- FEA, analysis of stress
- Tolerance analysis for effects of individual part tolerances on the easy of assembly and product performance
- Checking the interfaces between parts
- Generation of exploded views
- Generation of BOM

With assembly modeling CAD users can extend geometric modeling for construction, modification, and analysis of complex assemblies. Normally parts are added to assemblies by using special mating conditions or constraints. Assembly modeling is the key for virtual testing and creation of virtual testing environments. A virtual environment can provide much cheaper environment for testing and analysis. Direct modeling tools can make assembly design more intuitive and iterative. Normally complex assemblies include parts from many different CAD systems. With parametric tools this can cause lot of rework especially when assembly analysts are not developed CAD users (Direct Dimensions 2012).

5.1. Design-in-Context

"In-context design is a term used to describe the process of creating models of parts and assemblies within the context of other parts and assemblies." Typical history-based parametric modeling tools there are two different modes for working; part modeling mode and assembly modeling mode. User has to decide in the beginning of modeling process whether working with a part or an assembly. This makes sense because of history trees of parts and keeping these two environments separate is important with a history-based technology. This is because the system has to know which part or assembly history tree or the modeling or change operation will be recorded into. That is why the in-context design is naturally challenging in History-based systems. Systems can have special functionalities to work around the related complexities that come with history-based in-context design. Users still need to be careful not to use wrong level of assembly or part when making history-based in-context design.

With history-free modeling since there is no history tree to manage so neither there is no need for two separate environments. Users can create and modify parts and assemblies in contexts and simultaneously and there are no need for special in-context design functionalities. History-free can offer natural and powerful environment for top-down and in-context design. In the most developed level of top-down designing product development and modeling process have a strong fusion (Figure 31). Modeling tools are used in concept modeling as well as in making the accurate final models. In this case the evolution of the assembly is chronologically harmonious. When some product information already exists middle-out modeling can be used. Old parts are brought to assembly and after that parts needed can designed and modeled (Figure 32) (Haanpää 2010). In history-free environment assemblies are just structures and parts and subassemblies can be placed to the structure anytime. After parts and subassemblies are placed the upper level assembly manages and owns the position and relationship information between components.

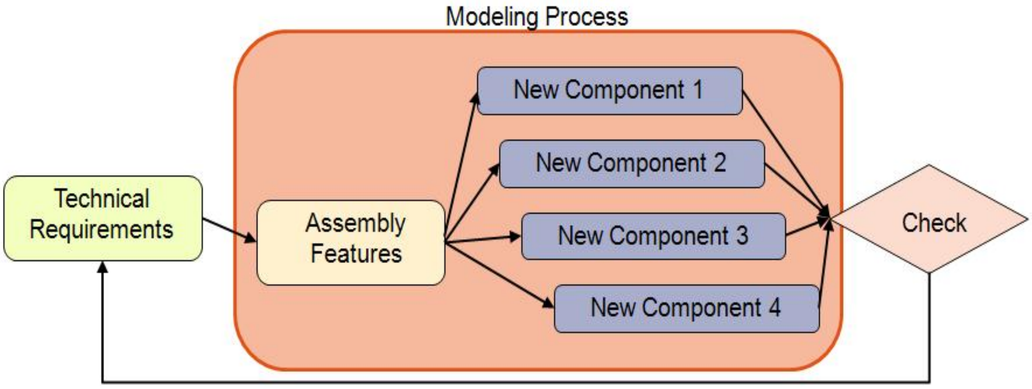

Figure 31. *Top-down design process. (Haanpää 2010)*

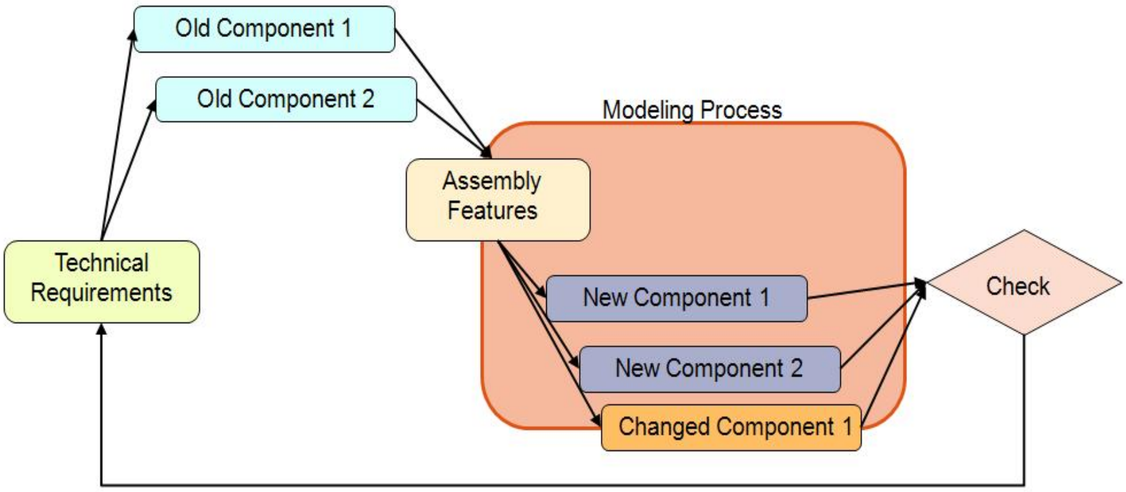

Figure 32. *Middle-out design process. (Haanpää 2010)*

This environment is like physical system and it makes modifications more natural. Natural environment makes creation of configuration easier and more iterative. Also configuration designing is faster since there is no need to change between environments during the designing and modeling process. Below there are modeling operations to consider between history-based and history-free assembly modeling (Jackson 2014):

- Modification of multiple parts with one sketch and one modeling operation.
- Creation of multiple, unique parts in one modeling operation.
- Modification of multiple parts with many sketches in one operation.
- Modification of a part by referencing geometry from another part/assembly.
- Moving multiple parts while modifying a part, in one operation and without constraints.
- Editing parts and assemblies in one environment.
- Creating multiple configurations in one environment.
- Saving a new item if working only in one environment.

Working in one history-free environment with parts and assemblies can bring more natural and flexible modeling platform but also it can be a challenge to engineering data management. At the moment most of the EDM systems cannot separate multiple solid bodies in one template to multiple items in library (Haanpää 2010).

5.2. Large Assemblies

In history-based CAD the collection of relationships and references can make models really complex. Because of that the load times are longer, out of memory errors can occur, performance of graphics is poor and problems in drawing creation can occur. This is happening specially when working with large assemblies. As 3D product designs become larger and more complex, they need more computing resources. CAD systems offer some tools and techniques that improve some consequences of working with large data sets, but use of tools requires special knowledge from modeling engineers.

Direct modeling can bring some high value opportunities to large assembly design and management. The technology behind direct modeling can greatly improve interaction with large assemblies. As direct modeling does not record the modeling steps used to create or edit the model, memory requirements and file sizes can be much smaller than in history-based system. Large assemblies normally contain 3D data from many different systems and that’s why there are many different file formats. As mentioned before direct modeling makes easier to use this external data. Data without history is also lighter than data with history tree (PTC 2011).

6. DRAFTING AND DIRECT MODELING

History-free and direct modelling have only small effects to drafting. The technology is normally used only with 3D geometry. With the tools 3D geometry can be generated faster, so drawings can be done also faster if the whole process is considered. But there are some special cases, in which direct modelling has a relationship to drafting. Direct modelling makes modelling easier and this makes use of CAD possible also to people who are not normally involved to modelling process. This can cause a risk that modifications are made to models that are not updated to drawings. Direct modelling tools are also part of developed 3D environment, where the role of the drawings is decreased.

One area where the direct modelling is related to drafting is reverse engineering. In this case it means when there is a need to change 2D drawings to 3D solid model. When models are generated from 2D the changes can be faster to make, parts can be used in assemblies, simulation, CNC-programming and virtual manufacturability planning. The process of changing 2D to 3D is simple. Lines of the 2D drawings are copied and used as a sketch in creation of the 3D model (Figure xx). With direct modelling tools this creation process is more intuitive and features are faster to create and modify (Naya 2012).

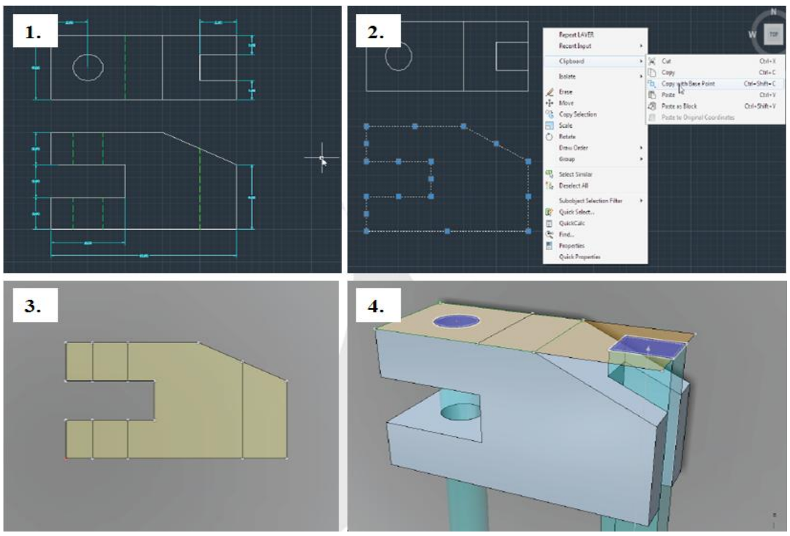

Figure 33. *Creating and editing 3Dmodel from 2D Drawing*

1 & 2: One view of fully constrained drawing is copied. 3 & 4: Copied geometry is extruded/revolved/swept and the modelling operations needed are completed.

7. PDM AND DIRECT MODELING

Even the benefits of direct modeling and history-free CAD are mostly in the area of modeling, there are still some characteristics in area of PDM to consider. PDM in this case means the environment where the modeling data is managed including data storage, access control and control of data forms. In some cases 3D modeling data can be managed with history tree, for example limiting edits by controlling parameters. Even with this parameters can be deleted and reordered, so the in fact the history tree is not preventing unwanted modeling changes without reasonable access control. Access control is good to do in PDM/EDM and modeling operations keep apart from this. CAD should provide good tools for handling the geometry, and PDM should provide visible and comprehensive platform for managing modeling data and data related to it (Mestre 2011).

7.1. Multi-CAD Environment

Last years the importance of multi-CAD PDM functionalities has increase. Models and assemblies are more accurate and complex and in assemblies and products there can be data from many different CAD systems. This sets a challenge to PDM and main CAD system used. At first PDM has to be able to manage multiple cad forms and then CAD need to have tools to edit data without history tree.

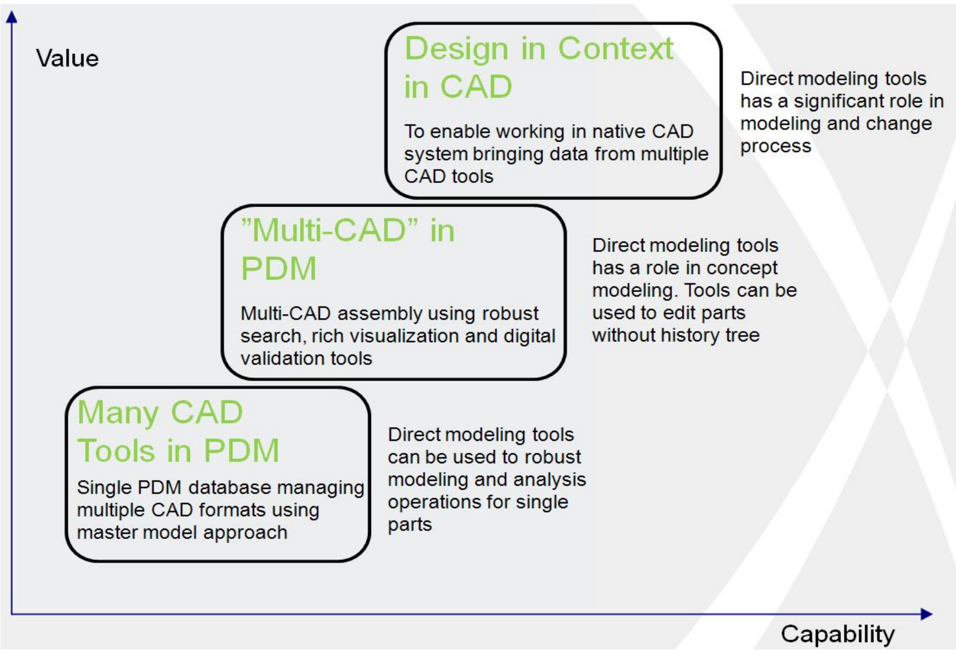

Figure 34. *Levels of Multi-CAD Environment. (Wujec 2011)*

At the first stage PDM makes possible to store multiple data forms. Parts and assemblies are used mostly to make manufacturing and assembly drawings. Components from partners or suppliers can be saved as a natural format of the models. Use of these models requires data transfer in some of the universal formats. The PDM system works as a database for modeling information (Mestre 2011). Direct modeling tools can make editing and preparation of the single models more robust.

The second stage of the multi-CAD PDM provides tools to create assemblies using multiple CAD-formats. Geometry is used to create constraints between parts and this leads to possibility to complete simulations. Different product concepts can be researched by using iterative methods and direct modeling tools. Also editing the parts from another CAD system without history tree is more intuitive with direct modeling tools. The most developed PDM level offers good visualization, assembly validation, configuration tools. PDM has capabilities to migrate data and use universal data format, e.g. JT, in product development process (Mestre 2011). Also engineers that normally are not involved with CAD have now possibility to use 3D visualization and designing to help product development. Modeling environment is intuitive and it has capabilities to fully use 3D information in simulation, manufacturing planning and analysis. All information related to product is easily available also during the designing and 3D modeling. Direct modeling capabilities are widely used to different operations.

7.2. File Size

Based on technology behind the direct modeling the modeling data file size can be substantially smaller. Complex references and relationships in the parts and assemblies are sometimes needed, but this data normally includes information which is needed. In history-free environment parameters and relationships needed are easier to recognize. In some cases history-free geometry can be 80% smaller than history-based geometry. This leads to better assembly management and lighter engineering data storage. The difference between geometry created using only parametrical tools and using also direct modeling features where possible bases on the difference of number of features, number of features types, number of design steps and number references.

8. INTEROPERABILITY BETWEEN CAD-PROGRAMS

In today's product development environment includes typically multiple CAD data formats. Neither it is not uncommon to find multiple 3D CAD systems inside one company. This can be result of company fusions, process driven requirements or preferences of the users and management. There are some best practices to work in this kind of environments. Things are depended on the processes and the tools that company has. 3D data from multiple sources can be managed in one system or in other case it can mean interoperability between multiple systems. Direct modeling tools can be used to edit transferred data.

8.1. Data Transfer between CAD Systems

Translation of the history or feature trees between the CAD systems is hard or impossible. History tree contains things like sketches, references, parameters defining 3D operation and relationships between modeling operations. History trees don't have any industrial standards to make transfer flexible. There are some special data migration tools to translate history tree, but normally even they don't manage to do complete transfer/migration. Because of this the geometry is only common data between 3D CAD systems. Geometry translation is possible through the universal CAD file formats like STEP, IGES, Parasolid and JT.

When translating a 3D solid model the model has to be "water-tight" and this is critical. Without connectivity of edges the translated model will be only a set of unconnected surfaces and edges. Edges have always a start point and an end point. Connected edges create loops, set of loops create faces and connected faces create solids (figure 35). To be connected the start point of one edge must match with the end point of another edge. How close these 2 points have to be that they are connected determines the accuracy level of the CAD. Most of the 3D CAD systems run at different accuracy settings and that makes transfer of the geometry more difficult (Mashahiro & Shigeki 2007).

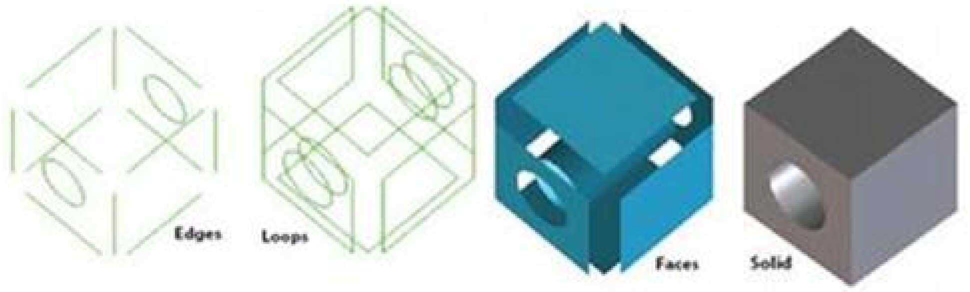

Figure 35. *How solid gets made. (LaCourse 1995)*

8.1.1. Best Practices with Interoperability between CAD systems

With some best practices the data transfer can be more predictable and waste of time with importing data can be avoided. Usually creating company width standards can be challenging because suppliers and partners might have their own ones. Company should have a standard for geometry accuracy. This will be the most effective step to take in developing a coexistence CAD strategy. The CAD accuracy can be lowered or raised depending on needs of the CAD environment. Understanding the impact of accuracy settings can be complex but there are few things to consider (Jackson 2014):

- CAD systems work best with geometry that has the same or higher accuracy. If the accuracy of the geometry has set too high, importing can be more challenging.
- Downstream operations of the model have to be considered. What is the accuracy level that FEM analysis and CNC-programs need?
- Accuracy level can impact greatly to the robustness of the system. Complex geometry can perform better with lower geometry accuracy.
- Most of CAD systems have also “heal geometry” tools. Understanding capabilities of these tools can greatly robust import operations.
- Use of the PDM system which accepts multiple CAD-formats.
- With standard accuracy an automatic model format translation can be used based on process requirements.
- Geometry translation should be done at a part level rather than an assembly level. Translation at assembly level results in a single file and data management can be very challenging.

8.1.2. Challenges with History-based System and Opportunities of History-free System

Considering all the research and work that has been done in the area of CAD data transfer it should be smoothly and mature. Interoperability has improved, but also modeling environment has changed more complex. There is more process where the 3D models are used and modified. Significant factor affecting data translation is the intelligence of

the 3D models. History-based CAD put lot of intelligence into the model. Intelligence includes sketches, feature definitions, constraints and structures. History-based systems work through this intelligence and information in the layers rather. Because there are no industrial standard for the intelligence translation, use of translated data in history-based CAD can be challenging. Some of the protocols can accommodate information such as dimensions and feature definitions, but the information required by the typical history-based CAD is different. Even the geometry is translates accurately, the possibilities to interact with it might be really limited depending the system used.
To manage interoperability issues there are some workarounds with history-based CAD. One method is to ensure that partners and suppliers use same system. Translated “dumb models” can be used as a reference when building intelligence models. Also a dedicated intelligent model translator can be purchased, but it means more steps to modeling process (Jackson 2014).

A history-free system or good direct modeling tools can greatly improve modeling processes related to the transferred data. Because tools are working with geometry, not with intelligence in the history-tree, issues related to interoperability can be avoided. With direct modeling tools also intelligence can be added.

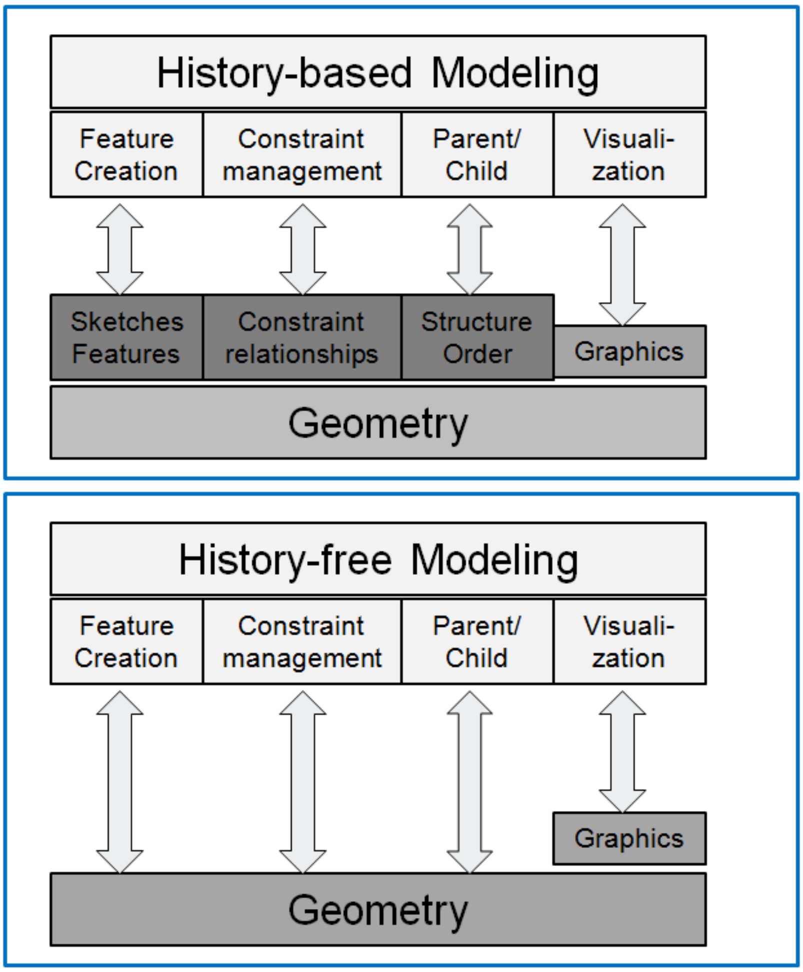

Figure 36. *Systems operating with geometry*

Coexistence of multiple 3D CAD systems in same process can be challenging, but with right tools and good data management it can improve product development process. Typically some trial-and-error will be required to find the best way of working with interoperability issues. Determining an acceptable and suitable CAD system accuracy level and transfer platform is really important for having the highest level of success.

8.2. Data Transfer and Working with Neutral Formats

Neutral CAD formats are defined by the industrial standards. Idea of these formats is that they can be viewed and edited in almost any CAD application. In this chapter is represented most common file formats and how they can be used in the modeling process and how the direct modeling technology improves the usage of these formats. The oldest but still widely used format is Initial Graphics Exchange Specification (IGES). It includes many relies on experienced designer. ISO 10303 is a standard for the exchange of product modeling data. This format is also known as STEP and it has many different configurations. Also parasolid and JT are well known data transfer formats provided by Siemens. Depending on programs used for export and import processes the results can vary a lot.

To find a best way to translate data, the processes and needs has to be understood. There are many kinds of needs depending on the process (Mestre 2011):

- *Speed and convince:* If the process needs to be fast and convince, data translation can be risk. In this case it is safe to stay in the native CAD files. Asking different formats from the model owner can cause delays in the process.
- *Managing risks:* Creating another translated model creates a need to manage another object of the same document. This can be risk, if there is no link to original model. How to manage versions after that especially if the data is sent out. Creating multiple documents of same model just adds complexity to the process and increases the risk of mistakes. These things have to be noticed when planning the translations in the process.
- *A valid and accurate solid model:* With data translation there might occur problems with the geometry of the model. Normally these problems occur when there are differences between sending and receiving system. To avoid issues with broken geometry accuracy levels should be known and variety of accuracy between systems should be avoided. This can be challenging when there is a need for models from suppliers and partners. Solid modeling is all about the connectivity, if there are no connections between edged, there are no valid solids.

- *An editable model:* If the receiving side is a history based and there is need for editable model the history tree with all of its components is needed. Also version of the same CAD system plays a big role when translating an editable model. Direct modeling tools offer possibility to edit models without history tree but this requires that receiving system includes robust direct modeling tools and users have knowledge how to use those. In this situation the decision to use geometry as a master has to be made.

Round trip of editable models and no data lose: Capabilities of the history-free CAD provides a good environment for these demands. When geometry is a master and there are no history tree components to carry with, the data loss is the minimum. All the geometry can be sent and received using most common neutral CAD formats, as long as accuracy levels are acceptable (Mestre 2011).

Typically modeling processes includes two or more of these components. Direct modeling tools integrated to history-based CAD is one solution, but it is only working in some of the cases. The best practices should be created based on process requirements and after that right tools can be chosen. Using a help of CAD venders is never bad idea when solving problems and creating solutions related to data transfer (Mestre 2011).

A standard format a geometry translation should be chosen in an early stage of creation of the best practices. The common choices are IGES, STEP, Parasolid, ACIS SAT and JT. Each CAD system may better support some particular format over another. After choosing the standard format for translations, the workflow validation needs to be done. This consist consideration of all actors and requirements related to the workflow. Direct modeling tools give freedom in the area of geometry when the history tree is not available in all cases (Mestre 2011).

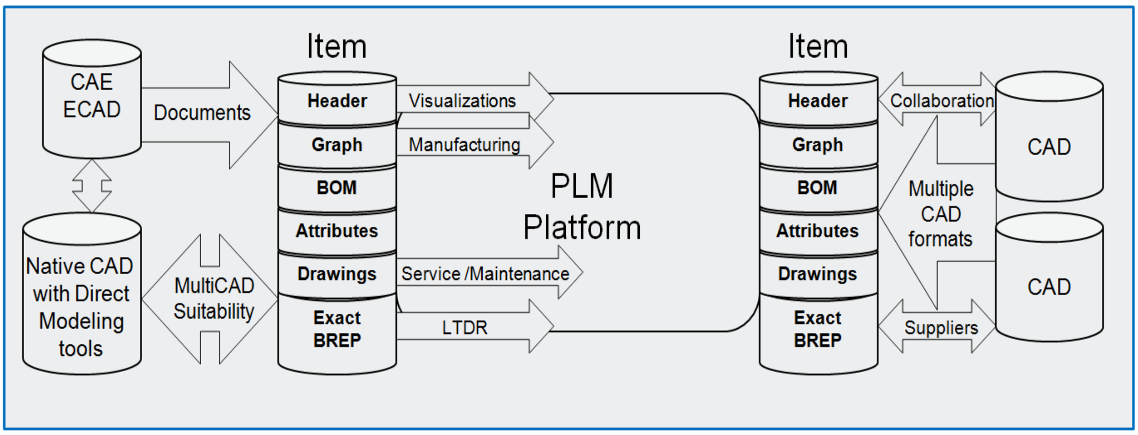

Figure 37. *Data workflow. (Mestre 2011)*

The figure represents the workflow from the CAD point of view. CAD's are providing design data that will be used for further operations. Direct modeling technology gives tools for creating and editing data from multiple sources. Technology also makes possible to robust the use of the data from partners and suppliers. In PDM/PLM system the data is managed and provided to other actors.

8.3. Migrated Models

One special group of transferred CAD documents are migrated models. For all organizations that have used same CAD systems for many years the need to migrate legacy data to a newer system will eventually arise. Migration is normally done when moving from CAD system to another or from older version to newer if there is no possibility to direct interoperability. Migration is normally done with special translation tools provided by CAD vender or some 3rd part actor. Legacy CAD data migration can be done in 2D, 3D or in both levels. Exchange of 3D model data is more complicated because of differing data representation, geometric tolerances and diverse modelling conventions and practices. These issues can lead to re-modelling, re-mastering and even design divergence (Mestre 2011). Migration can be done dynamically, “component migration is done when there is need for re-use” or all CAD data can be migrated at the same time. In both cases can be unexpected costs and delays in actual design process.

After the 3D CAD legacy data migration is done there are typically some modelling data lost. For example history tree, relationships, references, assembly structures and constraints are always problematic to migrate. If there is need for fast and flexible data migration, normally all or some of these characteristics are abounded. In this case the role of direct modelling tools can be significant to reduce re-modelling work and to increase amount of re-use. When the problems with migration and modelling data exchange can be avoided or skip, also the design process during the migration project and after that is more fluent.

9. DIRECT MODELING AND PRODUCT DEVELOPMENT

The product development process has nowadays close integration with information technology. Management and documentation of different product development process stages are in PLM system. CAD systems are used for designing and visualization of products. The process consists many decision making steps in which the basic science, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. In many cases the product development actors are focusing their arguments and discussion based on their own individual circumstances, experience and needs. Many times the bigger process picture has been ignored.

9.1. Computer-Aided Engineering Process

Product development tools can be put to three simple categories; creators, managers and consumers. Typically tools are combination of all three, but will focus on one more than another. Important thing is to understand do the tools support the process and how the process delivers value to the business. When making decision to implement new tools or improve old ones has to be understood what will be gained by making a move up and at what cost. The toolsets need to be in right place to support the proposed process improvements. Also the continually research related to tool replacements, additional tools, personnel needs, culture, future sights and practices is required.

Normally the PLM is viewed as a manager toolset. The role and importance of PLM depends the level of IT used in the product development process. Creator systems are providing a huge amount of data that has to be managed properly to be able to find, understand and extract as needed it through-out the process. Also the manager system normally creates the limit for development of the engineering process (Mestre 2011).

In product development one of the biggest creators is the CAD tool used. The geometry of the product is normally the main document what CAD is providing. But there is also a huge amount of data that is created and associated with this geometry. CAD is creating data like drawings, tolerances, notes, mass properties, materials, title blocks, engineering calculations, FEA results, manufacturing information, animations, simulations, images and marketing material. The time that is invested to create this data and the infrastructure needed to support and manage it can be remarkable.

There are some key characteristic what competitive product development process requires from systems. All relevant information should be visible to make well informed decisions. Product requirements need to have clear visibility and validation throughout the process. Flexible design tools are required to collaboratively develop and evaluate multiple design options efficiently and there have to be multi-disciplinary product development and product simulation tools to ensure product fitness of purpose.

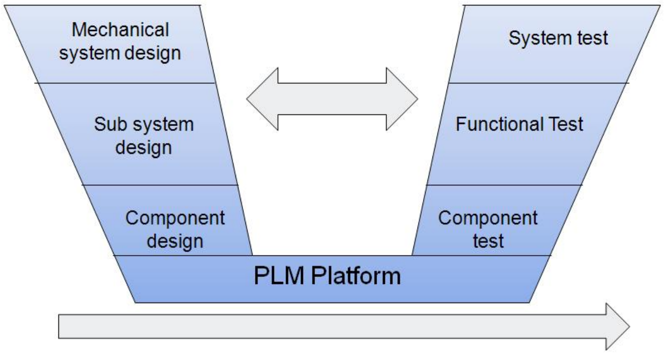

Figure 38. *Product development data flow and platform. (Mestre 2011)*

Engineers need the ability to work with multiple levels of detail, from coarse to fine product definition and have clarity of design requirements and their functional impact. The supporting information comes normally from multiple sources and engineers immediate access to it. Also visibility needs to be maintained and traceability of changes needs to be on proper level.

9.1.1. Product Information Sources and Consumers

The engineering process consists of many actions and actors and product information comes from typically multiple sources. All areas of the engineering need to be considered when designing complex products. The system engineering is a process for managing this complexity. The 3D model data is created mostly in mechanical CAD and some components can be imported from other CAD systems. This information is used in almost all the other digital operations. Changes to 3D model can cause lot of change management operations which can be time consuming and expensive if the product information is badly managed.

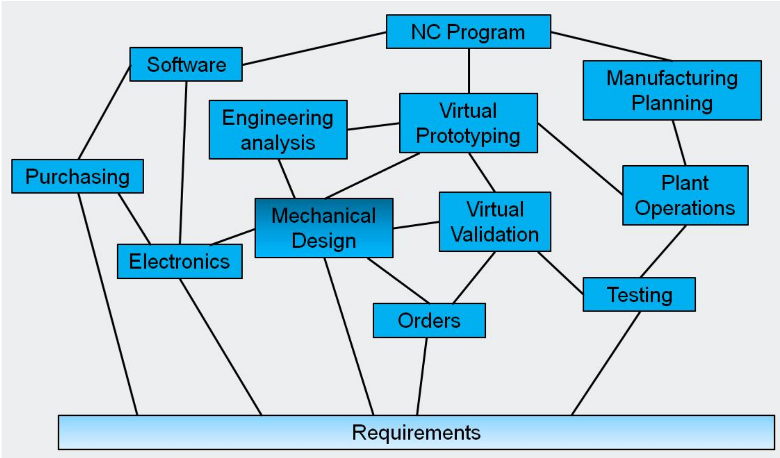

Figure 39. *Product information sources and consumer environment*

To have a good understanding of connections between actions it is important to know the semantics of relationships. 3D Visualization is good way to spread information around the operation network. The CAD tools is source of these information and that's why is important to have a flexible modeling tools to record engineering actions.

9.2. Direct Modeling in Product Development Environment

The role of direct modeling toolset is definitely creator. Technology can decrease the resources used to create and modify data and improve the quality of the data created. Like other tools, the direct modeling tool implementation needs to be based on business needs and there has to be proved value creation. Direct modeling technology has many areas where to use it in engineering and product development process. The biggest are is naturally the mechanical design. Technology can be used to improve creation and change process. Later on when 3D data is used for other operations, direct modeling tools can improve iterative testing and model preparations for analysis and manufacturing.

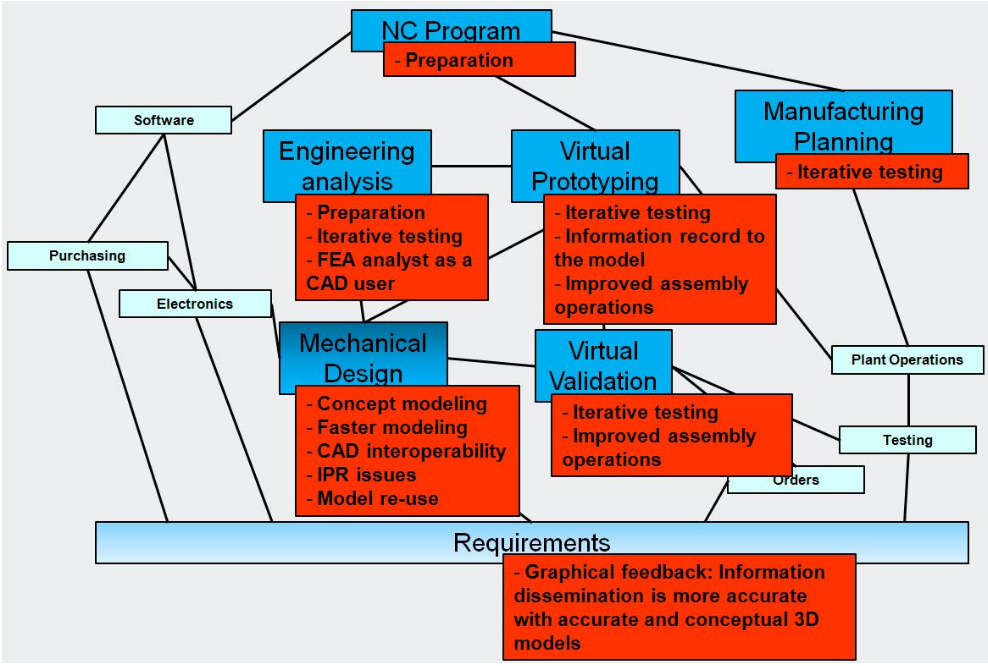

Figure 40. *Direct modeling in product development environment*

Direct modeling tools can be used especially in these stages of new product development project:

- **Concept Modeling:** During the concept modeling the ideas from inside and outside sources are collected. Ideas are organized and estimated from strategy, profitability, realization and grow point of view. Innovations typically based on these ideas and modeling is used for realize these ideas. Innovations are normally area that is in companies highly admire but tools for it are not clearly defined. One way to improve innovation is to increase volume of early stage concepts and ideas. Normally this is challenging because only some of engineers are CAD experts and modeling is too time consuming for iterative testing of different concepts. Direct modeling offers tools for faster response and more capability than whiteboard concepts. More engineers with suitable tools for concept mean more concept capacity (PTC 2011).
- **Pre-CAD Concept:** History-based tools are best used when design intent is completely understood prior to modeling. Using history-based CAD tool for concept modeling results typically too inflexible and bad-defined CAD data. Once the concept modeling is done with history-based CAD users are normally faced with 2 options: Re-create the CAD model properly and cleanly following the rules defined or release inflexible and badly modeled model for final documentation. Direct modeling tools are flexible with geometry so accurate models can be done by re-using concept models and also the required parameters can be created and unnecessary parameters can be deleted.
- **CAE Model Preparation and Creation:** Geometry editing is the classic problem for FEA and CFD analysts. Usually high-and-analysts are not CAD experts

because CAD tools are built for full-time designers. Analysts either try to get CAD geometry from the design department or attempt to build rudimentary geometry themselves with CAE pre-processing tools. Most geometry coming from the design department includes too much manufacturing information and details. Many sorts of features, for example fillets, chamfers, misalignments and some holes have to be removed before analysis or the solver will choke. Direct modeling tools give a possibility for CAE analysts to remove these features without special knowledge of feature-based CAD tools. Tools are easier to learn and they include functions to repair and simplify geometry automatically. This makes also possible to start analysis process before the modeling process is completely ready. The powerful geometry editing tool makes also easy to create realistic concepts and CAE simulation can begin to inform design rather than waiting until the design process is complete.

- **Manufacturing design & Test:** Test and manufacturing engineers are not neither CAD experts even they are creating jigs and fixtures based on CAD models coming from the design department. With direct modeling also these operations are faster and models can be used with more intuitive ways without huge model data transfer operations between manufacturing and designing.
- **Sales:** Bid modeling is really important area in sales. Sales engineers are collecting customer requirements and quote new projects. Sales engineers are rarely specialized for CAD modeling, so finally someone else has to do this modeling. If the number of responds for RFPs can be increased, also the bid wins and revenue can be increased. Using CAD designers for bid modeling is time consuming and inefficient.
- **Marketing:** Marketing is often re-purposing CAD design images for use on brochures and websites. In marketing driven company these workers also need to work through early phase product definition ideas.

9.3. Time-to Market

When modeling a new product, engineers often need to wait until the decisions at the stage before are done to make their own design decisions. Unlike traditional CAD modeling, where designers must know what the requirements and materials are before beginning to design, direct modeling makes possible to create as many design ideas as potentially viable. Trying different manufacturing and assembly concepts in CAD makes easier to figure out what fits the best in the certain case. Developing a deep understand of problems and risks before making the final designing decrease the need of late changes and the time-to-market can be reduced (PTC 2011).

When model modifications and concept models are created by the same person who is doing the analysis and simulations the process has lass steps. By decreasing the amount of modeling data sent between CAD designers and other departments the time-to-market can be reduced. Also virtual prototyping and productization are more intuitive with direct modeling tools, when the workers of these departments are not typically advanced with CAD systems. The CAD system shouldn't force decisions before the last responsible moment.

9.4. Innovations

It is not uncommon for innovation not to be one of the top business drivers within manufacturing companies. Time-to-market, design-for-manufacturing, low cost manufacturing and quality are the things that have filled the top spots in the company's business drivers. But still innovation is considered as a key to success and that is why a renewed interest with innovation in product development has been seen. Right decisions when selecting designing tools and creating product development process can have a huge impact on innovation creations. Interesting question is how can process support and encourage innovation. Innovation should be able to capture in a process. Normally process is thought as something that is serial and repeatable – like manufacturing a product. This serial process has been tried to capture and control many times. Unfortunately this kind of process control can stifle innovations. The process of innovations has been documented in many companies, but it is more important to understand what kind of innovation is beneficial to the business and how it happens (Jackson 2014).

Innovations certainly need creative people to create them. Creative people require interaction with other creative people and lots of information and data. They also need to have good practices for collaboration and ability to enter this information to make good and fast decisions. Creative people should be courage and enabled to make decisions. Tools and process should support this and at least tools should not make decision making more complicate.

The process of innovation is not the same than the process of detail design. The difference between these two is normally significant. There is no clear line between these two processes and innovation may occur throughout the entire process. That is why also the technologies need to be considered to support both processes. Overall business drivers need to be clear and how they impact the process of developing products. Also the characteristics of the product have to be clear. By using this information the requirement can be defined and right tools can be chosen. Some CAD tools are supporting innovations better than other but they can have some weaknesses on other areas. There are some common characteristics that are supporting innovation and concept design (Waters 2009):

- The ability to consider many different ideas (flexibility)
- Reviewing old ideas to come up with new ideas (leverage, reuse)
- Interacting with others at the idea level (teamwork, collaboration)

- Analyzing and comparing ideas

Depending on processes and product, these capabilities may bring more value to the design process and help with the innovation process. When having a decision of tool set implemented, the context should be clarified. Serious mismatch between tools and innovation process can even kill some ideas.

9.5. Product Development Costs

Decreasing product development cost is normal action also when developing product developing tools. License costs are the easiest and most straight forward way to compare and choose the solution with lowest costs. But this can have some effects that are not so visible. There are many second level costs that are influence of not using the right tool in right place. Also not knowing how the solution chosen works best is waste of money. Even knowing how to use a CAD tool doesn't make anyone a good designer, not knowing how to use a CAD is a problem. That is why there should be also some time used to estimate, test and recognize capabilities of the solution chosen (Rebrukh 2011).
Many times habits, culture and the path of least resistance often take precedence over process. Still 2D drawings are preferred method of conveying definition and design intent and the duplication of effort is normal thing in product development. Also lot of time and money is going for somewhere else than actual designing work. Direct modeling tools can reduce this time, when geometry can be kept as a master and the designing is done without many steps of creating different models for different use. There are much data created in product designing process that adds no value beyond the individual engineer (Siemens PLM 2010).

The best option to make more profit is not only to decrease to cost but also increase revenue (Figure 41). The creativity of the people should be captured and they should be able to use it where they think it is needed. With good tools there are more possibilities also to solve problems and especially notice them before extra cost is realized. Flexible tools make the collaboration inside the company and with outside suppliers easier and robust. And in the end using the 3D makes design environment more realistic and products can be simulated and costs estimated with less steps.

Figure 41. *Creating profit in product development process*

The most efficient stage in the product lifecycle to decrease the cost is product development. Cost of this stage is normally just few percents of total costs but with right decisions later costs can be affected critically. With good and iterative simulation and calculation tools in cad toolbox more possibilities can be estimated and problematic stages avoided before prototyping. Direct modeling tools are suitable for iterative testing during product analyses (Figure 42).

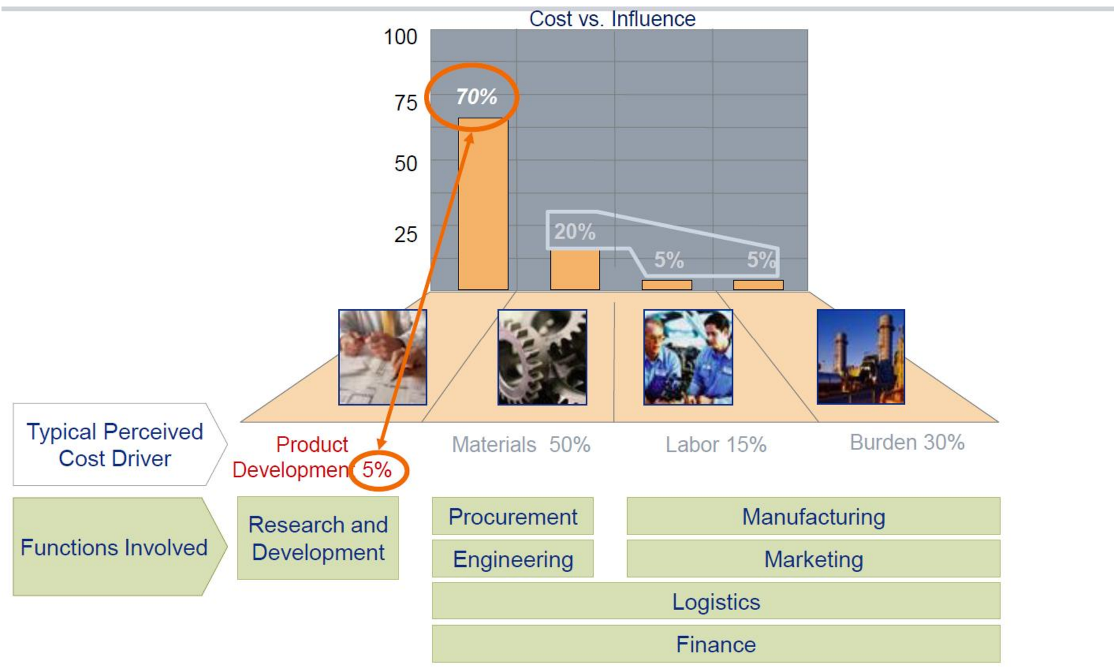

Figure 42. *Cost vs. Influence in product lifecycle. (Siemens PLM 2010)*

With Direct Modeling tools many of the cost related first and second level action can be robust. Also amount of lost or unusable data will decrease after implementing tools that can work with less level of complexity (Rebrukh 2011). Direct modeling tools can make analysis based iterative product designing more fluent and innovative, because of decrease of limits. (Figure 43).

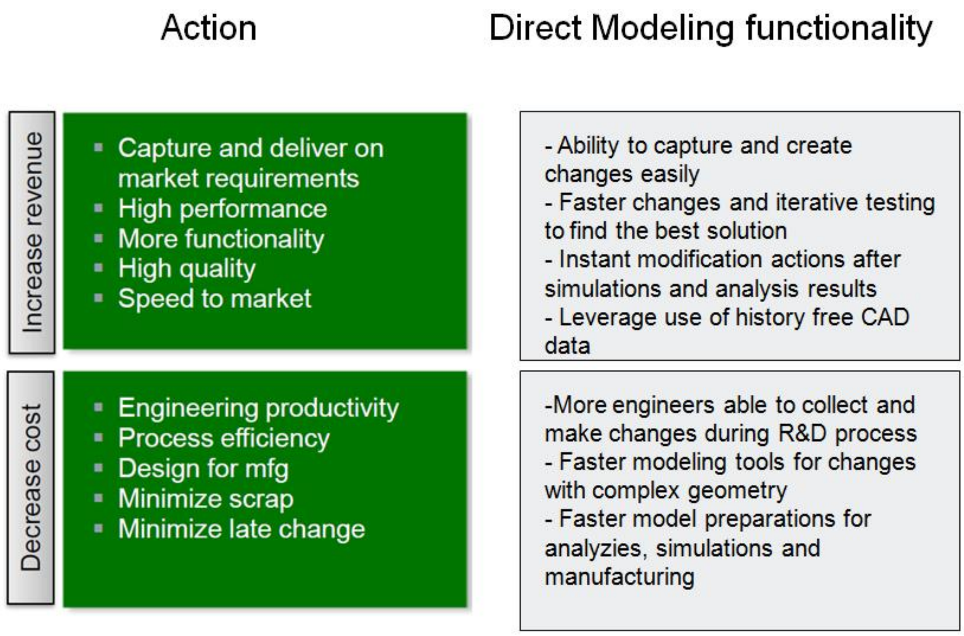

Figure 43. *Use of direct modeling tools to increase revenue and decrease cost*

9.6. Product Development and Direct Modeling Tools in Cloud

3D product development done in cloud can have some advantages and some risks. Advantages and risks depend the type of cloud used; private, hybrid or public. Cloud can improve performance of the design environment, it can provide better connectivity with designer and it can give easy and varied access to information. Commonly agreed risks with a cloud are data loss, IP issues and security of the cloud.

Cloud can make 3D organic free-form modeling possible where the surfaces and solids are in one integrated solution. Cloud can also provide computing power to make complex geometry and topology changes faster and more efficient. With direct modeling tools designing can be done in all common formats and cloud gives a platform where to open, edit and save these data. There are two bigger advantages using data cloud solution with direct modeling tools; collaborative working and access to the data (Siemens PLM 2010).

Collaborative: Connect people with the information they need:

- Sharing design ideas using the latest built-in social collaboration tools.
- Creating better products using the combined creativity and experience of networks.
- Accessing data anytime, anywhere, with secure data cloud storage.

Access: An affordable, easy, and fast solution that delivers:

- Reducing up-front expense with flexible and predictable term-based subscription options.
- Realizing design ideas faster using an intuitive interface and built in guidance.

- Getting faster from downloading to designing

Down side of using cloud services with direct modeling tools is difficulty to track changes done to the models. Once uploaded to cloud, original system loses the availability to record changes done in cloud. This can cause inaccuracy with revision/version information and lead conflict with assemblies.

9.7. IP Protection

CAD models often need to leave the secure confines of the CAD department to be shared with the outside world. It could be that your models need to be shared with customers or suppliers for collaborative product development. Need could also simply be to publish a digital product catalog showing envelope sizing for all products. It is critical to remove as much data as possible from these shared models to protect against the loss of intellectual property in the original CAD files. Sometimes Cad designers are used for these operations. Direct Modeling tools can provide effective way to delete and change important information from the models.

9.8. Finite Element Method

CAE analysts all too often rely on CAD designers for geometry. Typically, analysts must request often change when making design studies. There are two problems with this approach: CAD users are distracted from their core competency, detailed design, and simulation users must wait for changes need to be done to the model. Direct Modeling can shorten iteration loops by giving CAE users control of geometry, allowing CAE and CAD to occur simultaneously and even letting simulation play a guiding role throughout engineering.

Geometry is the classic bottleneck for FEA & CFD analysts. Most high-end analysts will never be expert CAD users because CAD tools are built for full-time draftsmen. So, analysts either get CAD geometry from the design department or attempt to build rudimentary geometry themselves in their CAE pre-processor.

Most geometry coming to the analysts from the design department includes way too much manufacturing detail. All sorts of fillets, chamfers, misalignments and nook need to be removed from the CAD model or the analyst’s mesher or solver will have a perform issues. Analysts using Direct Modeling tools can have a much better chance of pushing CAE upfront in the development process. With more powerful tools for creating realistic concept models easily, CAE simulation can begin to inform design rather than waiting until the end of the process when most design work is complete (Ronge 2010).

10. ROLE OF HISTORY-FREE MODELING IN TARGET COMPANY

Since direct modeling is becoming more popular most of the CAD software packages have direct modeling tools built-in or available without extra cost. This leads to the fact that all direct modeling tools are available unless the use is appropriately prevented. Implementing should include training and testing which has to be done with real business cases. At first stage implementing should be targeted to the users with the tasks direct modeling can provide a more efficient way of working.

Metso's product design should continue to use parametric modeling methods, but direct modeling can provide added value for CAD users. Metso's design process and user habits lay on the foundation for the efficient use of parametric modeling, and according the studies there is no need to change this. However, the available direct modeling tools should be taken into account in the future product development processes. Also, the existing direct modeling tools should be part of the training new users.

10.1. Direct Modeling as Part of Product Development and Modeling Processes

In Metso benefits of using direct modeling tools can be reached in particularly preparations of the FEM analysis, migrated data editing, correcting and simplifying 3D models. The figure below shows the NX and Inventor environments, processes and collaboration between these two systems. More significant role of direct modeling in the process is marked with red color.

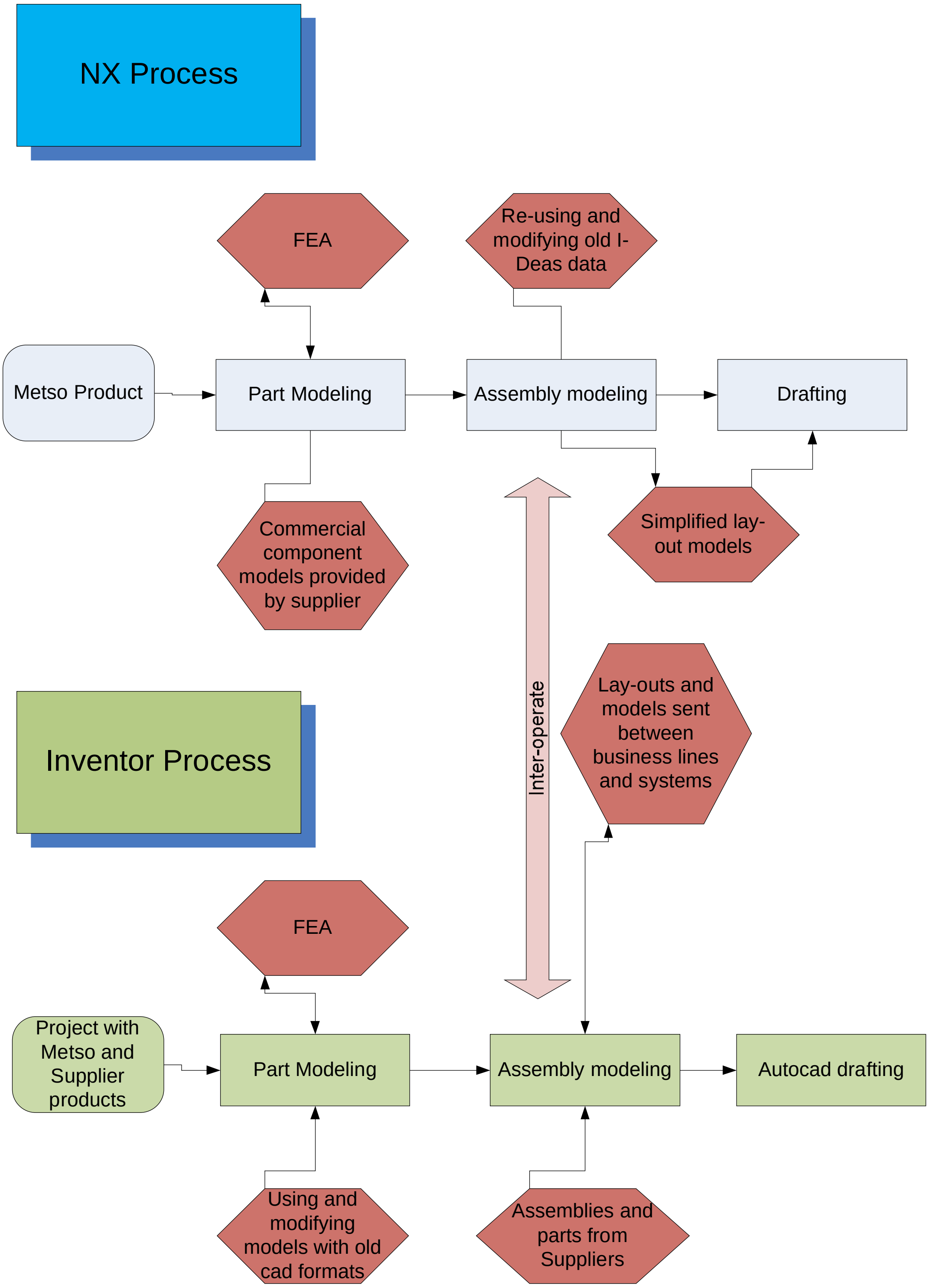

Figure 44. *Metso Design Process and Direct Modeling*

NX users had transition during 2008-2012 from I-Deas use to NX use. I-Deas data was translated into NX format without parameter history, so editing this data requires direct modeling tools. Inventor users have some old modeling information on Pro/E and Solidworks cad formats and translating this data with the history feature is really challenging. The models, however, can be modified Inventor Fusion software, without the need to bring feature history of the old models into new system.

In Metso external software are mainly used for FEM calculation. Importing data to FEM software are usually done in step format, which means the loss of feature history. Therefore, the models need to be prepared in the original format for the analysis. Often, however, FEM Analysts are not experienced CAD users and the preparation of the models can be challenging with feature based cad. With direct modeling tools models can be modified without understanding the feature of the history, and thus the process can be speeded up. FEM Analysts should receive training direct modeling tools as part of their training in CAD.

Metso's engineering departments are using a lot of sub-contractor models. These models often include unnecessary geometry for Metso, which makes models heavy. Also models have often broken geometry, which causes that the mass calculation macro behavior and the topology modifications becomes unpredictable. Therefore, the models are often corrected and simplified prior to their usage. Direct modeling tools provide more opportunities to fix the broken parts models and simplifying geometry by removing features. New technology provides opportunities for sending information between product lines and making lay-out design.

10.2. Role of direct modeling in the future

Since direct modeling tools were introduced their popularity has been growing. Most of the cad vendors have added direct modeling tools as a standard to their products. Also there is available cad software that only works with direct modeling methods. Even popularity is growing and new applications of tools are invented, old parametric modeling will stay as a back bone for many 3D designers and draft persons.

One big leap for direct modeling usage could be new controlling methods for 3D modeling. If picking up and moving faces and features of the model would become more interactive, then direct modeling methods would have a big advantages compared to parametric model controlling. Having and using direct modeling toolkit will save some time even using normal controlling methods and it also makes possible to involve more people for product designing process. The conclusion is that no one should overlook direct modeling possibilities when creating and updating modeling, product designing and engineering processes.

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