Interference checking
-
Computer Optimised Design meets Modularity

ENSCI - CTC 2015/ 2016
Masterthesis
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“Since new developments are the products of a creative mind, we must therefore stimulate and encourage that type of mind in every way possible.”

George Washington Carver

École Nationale Supérieure de Creation Industrielle - CTC 2015/ 2016 - Saskia Deschan - Interference checking

INDEX

Abstract

A separated and recombined system is called modular. Modularity itself can happen in almost every field in our daily life. However the meaning of the word may variate in the different sectors where it's used.
Particularly in design and architecture "the modularised elements are split up and assigned to modules according to a formal architecture or plan." [1] Therefore modularisation serves the purpose of managing complexity, enabling parallel work and tolerating uncertainty. After Baldwin and Clark "tolerant of uncertainty" means "that particular elements of modular design may be changed after the fact and in unforseen ways as long as the design rules are obeyed."[2]
Specially in the modern world the context of space and society both in architecture and in industrial design becomes more and more important. Therefore modularity implys innovation and may not only be seen in the context of space but also in the context of an object. Consequently spacesaving has to start with the individual object itseld to achieve the most optimised design solutions.
To solve the resultant issues that come along, certain design strategies must apply. Referring to this there is a diversity in interpretation of several processes available. Besides the already since hundreds of years existing manual procedures, new methods are taking place in the design process. Thanks to the industrialization since the second half of the 18th century, tools were developed further and machines were invented.

Concept of a modular smartphone
Source: http://weburbanist.com/2013/11/05/phonebloks-unlocked-google-backs-modular-mobile-phone/

Modular sofa by Hans Hopfer
Source: http://www.designcurial.com/products/mah-jong-modular-sofa/

1 Baldwin, Carliss Y. and Clark, Kim B.: Design Rules, Volume 1, The Power of Modularity, Stanford University, 12.01.2001, p. 5
2 Ibid.

Following developements in the 1950ies until the 1970ies paved the way for the digital revolution in the 1980ies until today.
Resulting of the proceeding scientific findings new systems were invented which offer the possibility to concept ideas with new methods. **CAD** and **CAE** programs revolutionised the design process and became inevitable.
In this context the term "**interference checking**" which is used in CAD and CAE is of importance. It may be understood as a verification if connected surfaces are closed after assembeling different parts of an object which consequently leads to improvements in the production as it saves time and development costs and therefore increases productivity. Although the term in context of this paper may not be constrained by it's original definition. It must be understood as an allegory that's figuratively describing the paths of an optimised design process.
Connectedly this paper brings up the term "computer-optimised design" and therefore shall discuss the need of CAD and CAE in the design process to achieve innovative solutions and modularity in objects and consequently follow the path of innovative products in the context of space and society.

Modularity in cameras
Source: http://www.lightingrumours.com/modular-design-7027

A modular USB stick
Source: http://inspirationfeed.com/inspiration/55-creative-examples-of-usb-designs/

Modular playground design by Kodomo No Kuni
Source: http://zirnspiration.blogspot.fr/2011/07/design-modular-architecture-pt-1.html

Introduction

“Earth provides enough to satisfy every man’s needs, but not every man’s greed.”[1]

The tendence in industrial design was always to invent objects which are functional or even multi-functional and therefore innovative in their use. Our society is growing but our planet stays the same consequently we have less space available and therefore the context between object and space becomes more and more important.

Source: http://www.dubai-oasis-capital.de/de/dubai-wachstum.php

1 Quote by Mahatma Gandhi

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Accordingly there is a need of space saving ideas which means the factor of modularity is inevitable. Modularity in this context therefore not only means the optimisation of space in architecture but also the optimisation of objects connected to the space they are used in.

Modular interior architecture in the japanese culture; modular in this context is referering to the function of the space
Source: http://www.minimalisti.com/living-room/11/living-room-in-japanese-style.html

These objects can be furniture...

Modular sofa; unknown designer
Source:http://www.floatproject.org/furniture-2/unusual-ideas-modular-living-room-furniture

... or tools for the daily use!

A Swiss Army Knife combines 12 functions in one object.
Source: http://www.knifecenter.com/knifecenter/sak/

Introduction

In agreement with **Dieter Rams** there are 10 principles for good design:[1]

1. Good design is innovative
2. Good design makes a product useful
3. Good design is aesthetic
4. Good design makes a product under standable
5. Good design is unobtrusive
6. Good design is honest
7. Good design is long-lasting
8. Good design is thorough down to the last detail
9. Good design is environmentally-friendly
10. Good design is as little design as possible

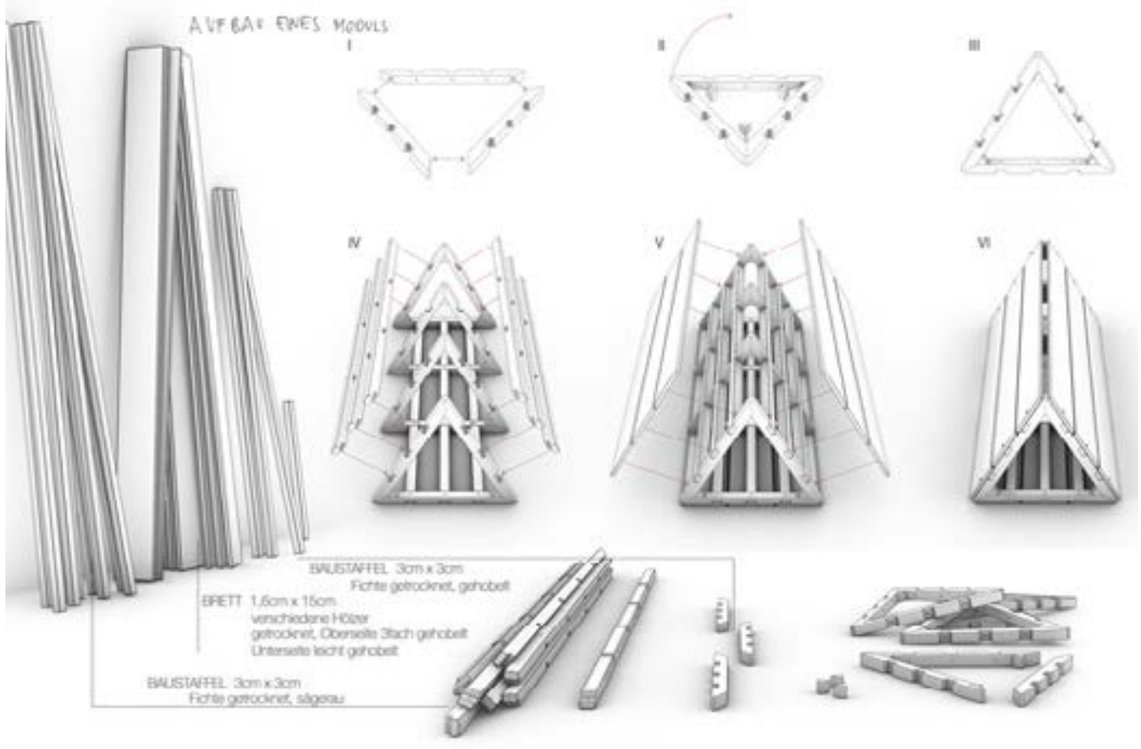
All these rules apply to this paper as well with the little twist that nowadays the context of space is even more noticeable than in the 1960s and therefore the use of modularity inevitable.
So what is the importance of modern techniques to achieve the requested innovations? Consequently what do we expect from an object? What does society really need and therefore what is the role of the designer to solve those problems? How can we improve our daily life and preserve our planet?
Obviously those questions aren't new but their definition changes from generation to generation.
In this context designers today can benefit of the advanced computer science and therefore use computer-based helpers to optimise the design, the process of creation and it's process of manufacturing.
The keyword is **COD** - computer optimised design.

1 https://www.vitsoe.com/eu/about/good-design

RT 20 tischsuper radio, 1961, by Dieter Rams for Braun
Source: https://www.vitsoe.com/eu/about/good-design

Dieter Rams, Braun clock radio (ABR 21 signal radio), 1978; design: Dieter Rams and Dietrich Lubs.
Source: http://www.domusweb.it/en/design/2011/12/28/dieter-rams-making-systems-and-making-sense.html

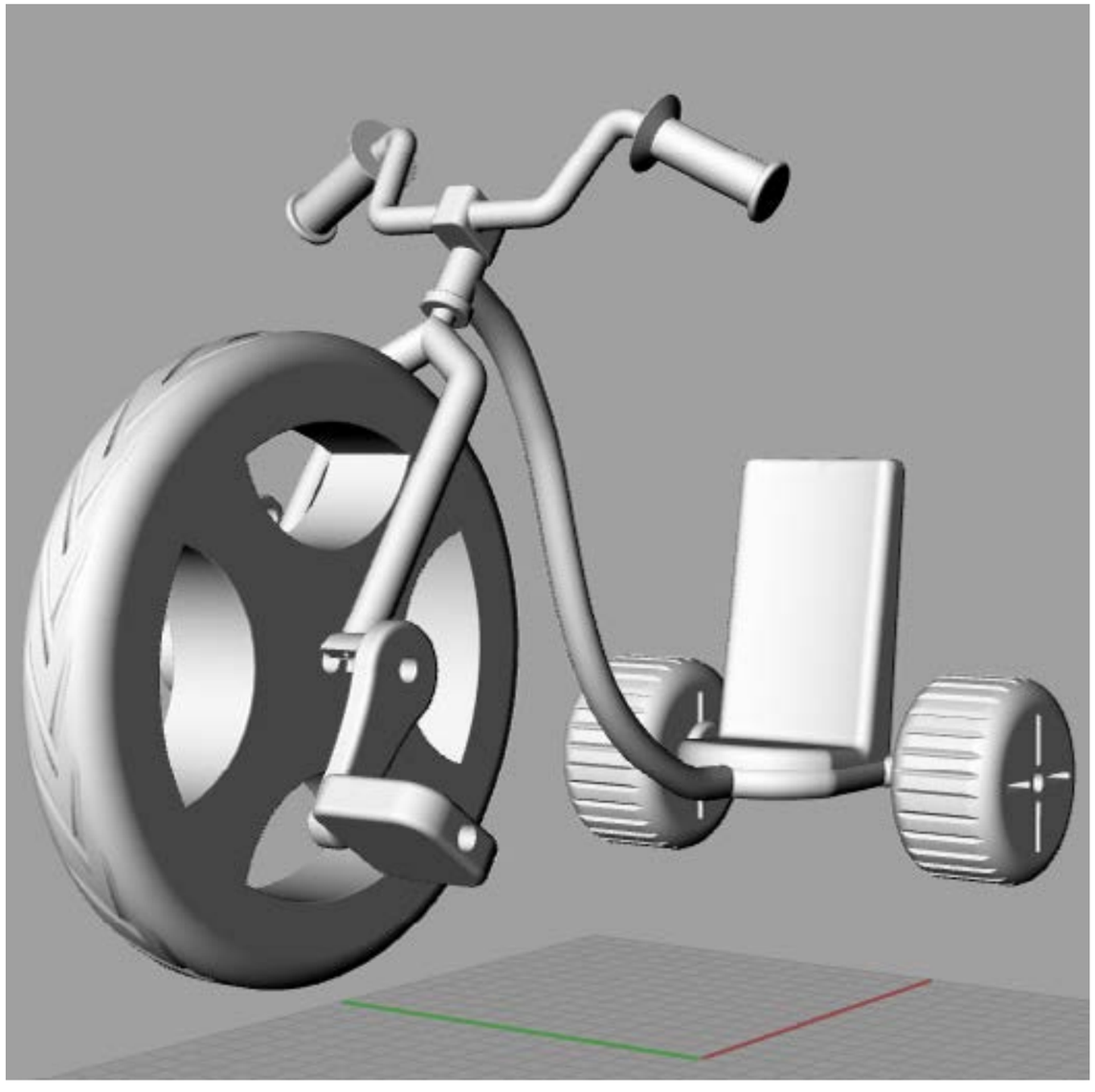
Computer optimised design means that the design of an specific object is thought-out in it's development steps with CAD (computer-aided design) and CAE (computer-aided engineering) programs. First one is used for 3Dmodeling, second one for optimisation and analysis.



Eckband Ost designed by Prechteck
Source: http://www.yankodesign.com/2012/03/20/large-scale-modularity/

Introduction

Following are examples of the rendering quality in different CAD programs. Even though those aren't modular or space saving ideas these pictures give a good first impression of the possibilites of the programs.



Final rendering in Rhinoceros
Source:http://gardclaystudios.blogspot.fr/2012/05/3d-printing-and-rhinoceros-3d-cad.html

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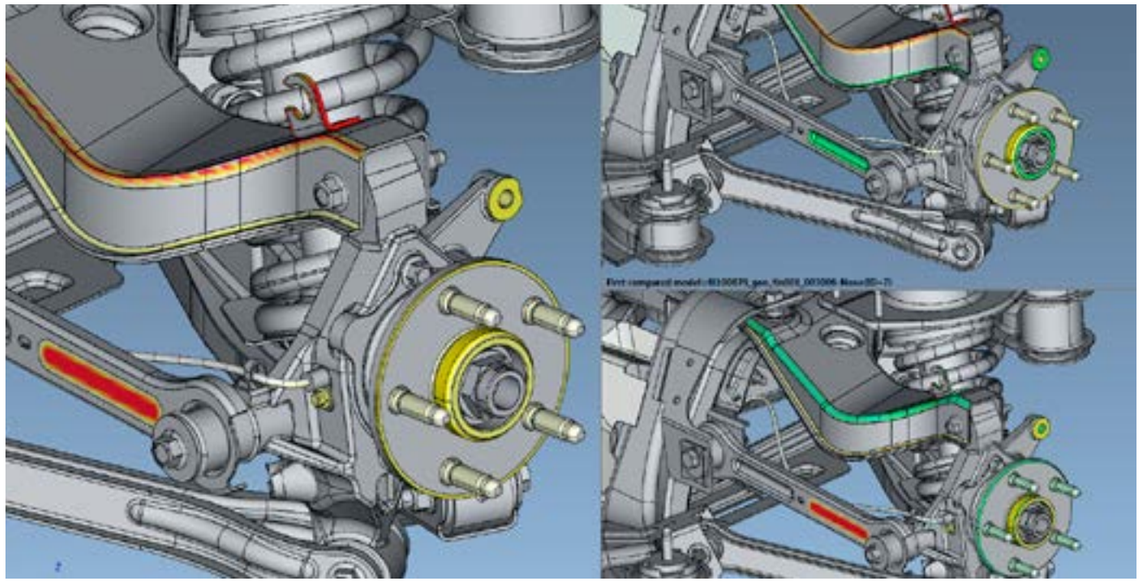


CAD validation of a car axes
Source: http://www.directindustry.com/prod/coretechnologie/product-24876-1075991.html

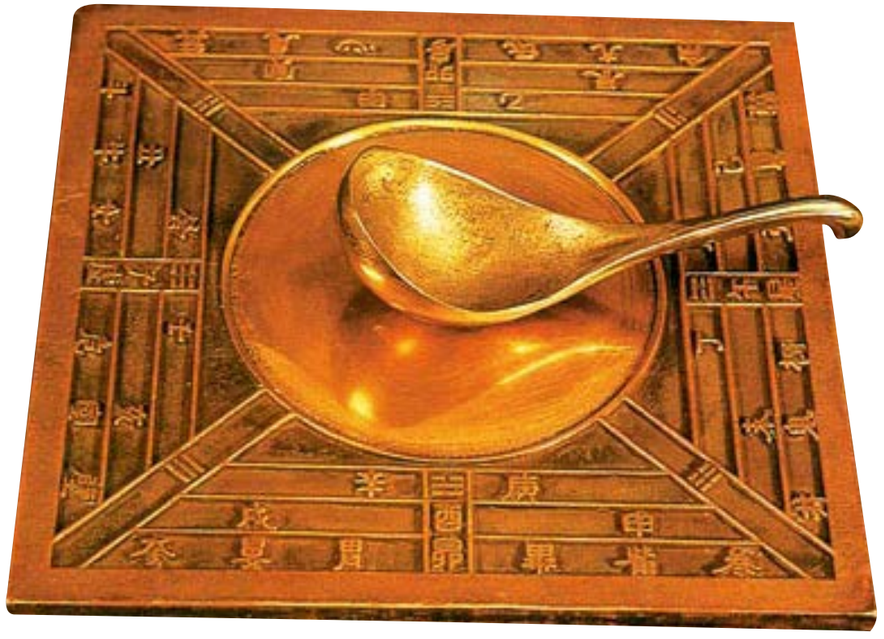
Final rendering of a futuristic turbine in Solidworks
Source: http://www.javelin-tech.com/blog/2015/09/how-to-assemble-your-parts-in-solidworks/

Modularity

3.1. Innovative Design

The term itself can be a widely understood manner. Generalised innovation means finding more effective solutions for devices or processes. Technically it may be seen as an application of better solutions with the need of new requirements. Doesn't matter if in products, processes, services, business models or technologies.
Consequently innovation is not only original but also more effective and interactive for our society.

Mesapotamian wheel around 3500BC
Source: http://www.ancient-origins.net/ancient-technology/revolutionary-invention-wheel-001713



Ancien chinese compass. Around 10th cenutury
Source: http://english.visitbeijing.com.cn/play/culture/n214962486.shtml

Particulary in the context of society and space, designers and architects have to face new challanges ever since human kind became civilised. This might sound exaggerated but is theoraticly exactly what happened. Even though in the old days the demands of the society were different and there was no such definition as "designer" or "architect", the métiers themselves were already existing without notification. Those people were artists, inventors, city planners or only average working man like carpenters. The need of finding optimsed solutions in different daily fields was given ever since.

Which seems like an implicitness for us was pioneering for people 100 years ago (see following pages).

Ancient nail. Already the old egypts used nails - around 3400 BC
Source: http://www.abovetopsecret.com

Modularity

The first light bulb by Thomas Edison
Source: www.edisonmuckers.org/thomas-edison-light-bulb/

The Blake Transmitter: Invented by Francis Blake as the first successful telephone transmitter
Source: http://www.sparkmuseum.com

Ford Model A from 1903
Source: https://blog.hemmings.com/index.php/2012/12/12/worlds-oldest-ford-motor-company-vehicle-to-help-celebrate-henry-fords-150th-birthday/

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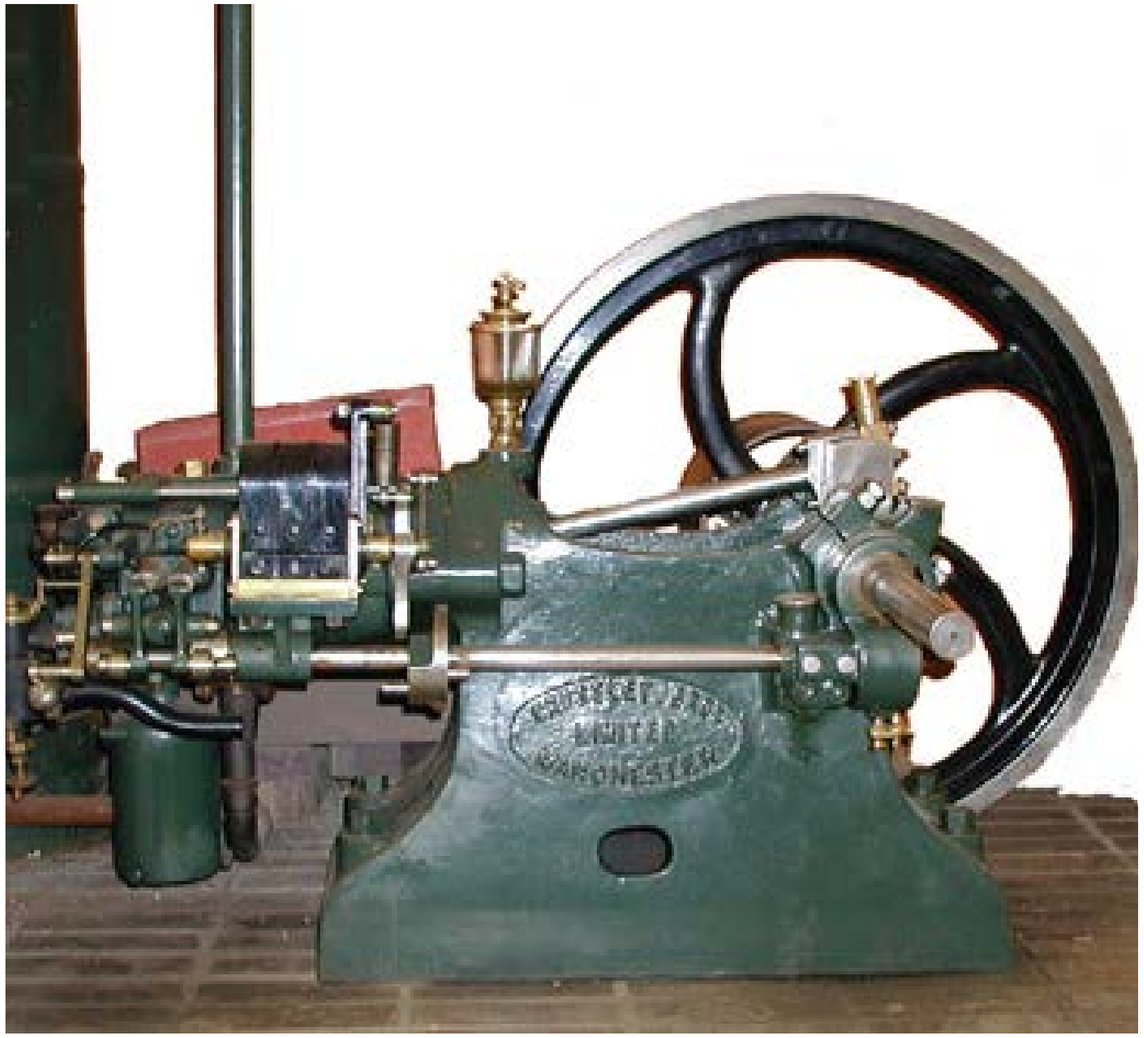


The internal combustion engine
Source: http://www.diracdelta.co.uk/science/source/e/n/engine%20configurations/source.html

Modularity

3.2. The need of modularity

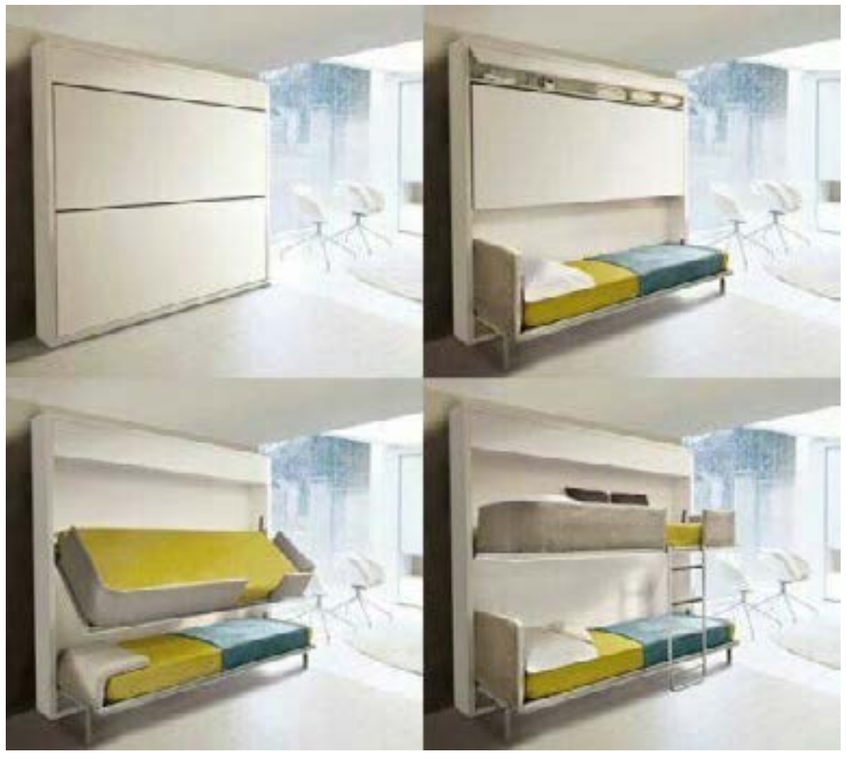
Our society takes living in such an advanced era for granted and people don't see that getting to this state of development not only took thousands of years but also the constant demand of innovation. We know what a wheel is and how to use a telephone but nevertheless we aren't done yet with improving our world. Especially in the context of society and space. Right now we are in need of space saving solutions to absorb the immense population growth that happened until 1962.
Architecturally seen this problem is trying to be solved since the early 20th century, from a design point of view creators just got started. The tendence leans towards creating functional or even multi-functional objects rather than luxery goods or only decorative products. Consequently the factor of modularity becomes more and more important. Modularity in this context therefore has to start with the object itself not only with the range it is used in.

New York City hosting 8.4 million people
Source: http://www.1zoom.net/Cities/wallpaper/147693/z330.6/

Residence in Berlin
Source: http://www.faz.net/aktuell/wirtschaft/immobilien/amtsgericht-kippt-berliner-mietspiegel-13587833/wohnblock-in-berlin-13587841.html

Modular interior design: A modular kitchen system by Kristin Laass and Norman Ebelt. The kitchen doesn't need more than 1m2 when it's closed. It includes a dining table, an induction cooktop, a refrigerator, an oven and storage space.
Source: http://worldhousedesign.com/tag/modular-kitchen/

Modular extension: Creating living space; project Drop House
Source: http://vi.sualize.us/drop_house_algeco_modular_alinea_prefab_antoine_cordier_olivier_charles_armel_neouze_architecture_picture_CAo.html?PageSpeed=noscript

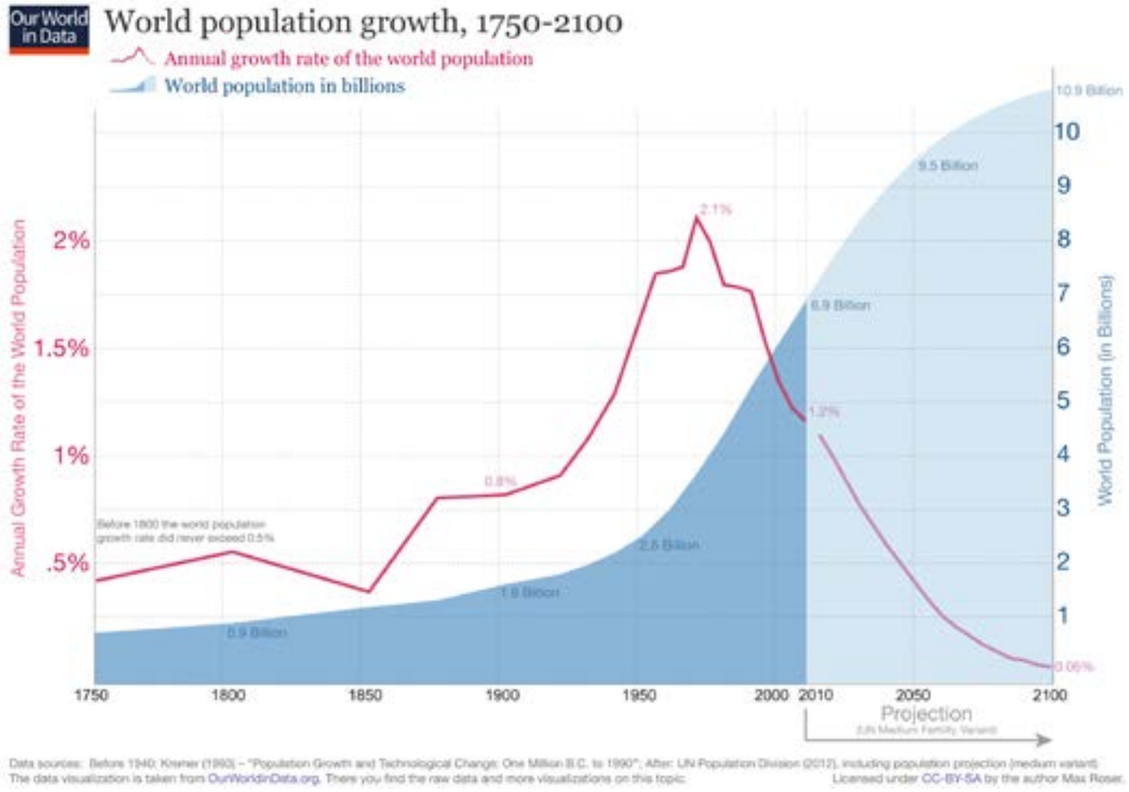


Space saving idea for small appartements
Source: http://designbump.com/30-clever-space-saving-design-ideas-for-small-homes/

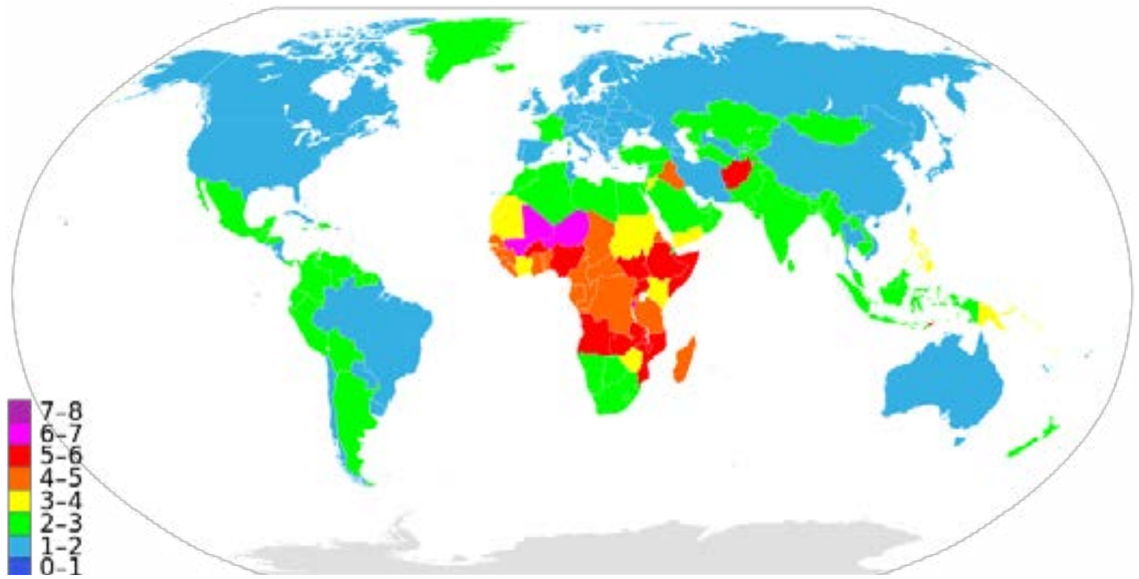
Modularity

According to the statistics the increase in world population between 1900 and 2000 was three times greater than ever before in human history. In one hundred years the numbers grew from **1.5** to **6.1 billion** people.
The visualisation down presents the annual population growth rate. The population growth rate never passed 0.5% before 1800 whereas in the first 50 years of the 20th century it increased from 0.8% to 2.1%. After the highest annual growth in 1962 the numbers go down again.

The projections estimate a growth of 0.06% for 2100.
Summarised around 108 billion people have lived on this planet which means that around 6.5% of all humans ever born are alive right now.
It is necessary to see and understand those numbers in order to understand the connection between space saving ideas, the need of modularity and innovative technologies.



Visualisation of world population growth
Source: https://ourworldindata.org/world-population-growth/



A world map showing global variations in fertility rate per woman, according to the CIA World Factbook's 2015 data.
The different colours show the average number of children per country.
Source: https://en.wikipedia.org/wiki/File:Countriesbyfertilityrate.svg

Modularity

3.3. What is modularity?

A separated and recombined system is called modular. Modularity itself can happen in almost every field in our daily life. However the meaning of the word may variate in the different sectors where it's used.
In biology, modularity is the concept that organisms or metabolic pathways are composed of modules. In construction, modules are a bundle of redundant project components that are produced en masse prior to installation. In industrial design, modularity refers to an engineering technique that builds larger systems by combining smaller subsystems etc. Particularly in design and architecture "the modularised elements are split up and assigned to modules according to a formal architecture or plan." [1] Therefore modularisation serve the purpose of managing complexity, enabling parallel work and tolerating uncertainty. After Baldwin and Clark "tolerant of uncertainty" means "that particular elements of modular design may be changed after the fact and in unforseen ways as long as the design rules are obeyed."[2]

Modular childhood - Lego
Source: http://visitlegoliberty.com/

Modular steelbuilding from Shift Modular
Source: http://www.shiftmodular.com/

1 Baldwin, Carliss Y. and Clark, Kim B.: Design Rules, Volume 1, The Power of Modularity, Stanford University, 12.01.2001, p. 5
2 Ibid.

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Specially in the modern world the context of space and society both in architecture and in industrial design becomes more and more important.
To solve the resultant issues that come along, certain design strategies must apply.
Besides creativity, technology plays an important rule. Nowadays designers and architects have the help of computers to optimise their design which can preserve time in the manufacturing and construction.

Modular construction of a timber house
Source: http://raconteur.net/business/top-ten-construction-innovations

Modularity

Historically seen the use of modularity in fine arts (thereunder architecture and design) has a long origin among different cultures.
In tradtitional japanese construction for example, the context between furniture and space was often determining the concept of the architecture.
A room was not separated by walls but sliding doors, so it was possible to arrange the space individually and therefore allowing the internal configuration to be customized for different occasions. The combination of standard rice mats called “Tatami” were often used as a measurement for the whole room. One mat was around 180x60mm which was approximatly the proportion of a human body.[1]

Japanese traditional interior
Source: https://fr.pinterest.com/Rachie8D/japanese-housing/

Ancien japanese living room.
Source: www.hokkaidolikers.com/en/articles/1109

1 Parent, Mary Neighbour. Japanese Architecture and Art Net Users System. Irimoyazukuri, retrieved on April 16, 2011

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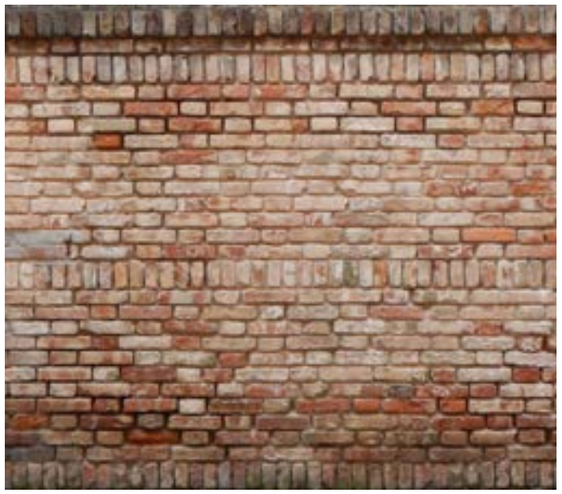
Staying in japanese culture in connection to product design the best example might be the Bento-Box. Bento is a form to serve food in a therefor special box that seperates the different dishes through little dividing walls or seperate components. Consequently each meal can be arranged in another order.

Ancient traditional bento box (Meiji 1868-1912); Dimensions : 27,5 cm x 27,5 cm x 27,5 cm
Source: http://www.kominguya.com/en/-vaisselle/140-boite-a-bento-ancienne-en-bois-laque-sur-pieds.html#idTab2

Antique japanese stacking tray bento box
Source: https://www.liveauctioneers.com/item/10101823_antique-japanese-stacking-tray-bento-box

Modularity

Furthermore modularity as a means of measurement is intrinsic to certain types of building. A brick construction for example can widley be considered a modular system as one brick connects dimensions that are multiples of the original unit.
In the 20th century with the rise of modernisme advanced construction techniques transform modularity from a compositional attribute to a thematic concern in its own right. In the 1960ies modularity becomes an autonomous artistic concern of its own and several minimalist architect and industrial designers adopt it as their central theme. Even if modularity started with architecture, nowadays the need lies already in the object itself and therefore it is a necessary consequence.



Brick wall - a modular system
Source: http://www.lughertexture.com/bricks-walls-textures-free-hires/bricks-new-clean/european-bricks-wall-1672

Modular “plug and play” building to test sustainable systems, materials, and technologies. “NEST will be a dynamic demonstration platform where researchers can insert and test various components building modules.”
Source: http://inhabitat.com/switzerlands-nest-high-rise-is-a-modular-test-bed-for-the-future-of-green-building-technology/

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BodyBi of Andres Scarpellini
Source: http://www.coroflot.com/andreascarpellini/furniture

Brianna Coffrey - The perfect bottle born stainless
Source: http://www.tuvie.com/the-perfect-bottle-modular-stainless-steel-bottle-by-brianna-coffey/

Modularity

Kewb-The space saving, multifunctional furniture
Source: http://www.hometone.com/30-mind-boggling-modular-furniture-units.html

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Boaz Mendel - Modular chair
Source: http://www.greenprophet.com/2011/08/modular-loop-chair/

Modularity

Convertible sofa/bunk bed by Bonbon
Source: http://www.hometone.com/30-mind-boggling-modular-furniture-units.html

Space saving idea for small appartements
Source: www.timisconstruct.ro/articole-si-noutati/noutati/mobila-ingenioasa.html

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Modularity for all surfaces by Patricia Urquiola
Source: http://www.flor.com/blog/modularity-for-all-surfaces/

Transformer shelf by Martin Saemmer
Source: http://netdiver.net/modular-design

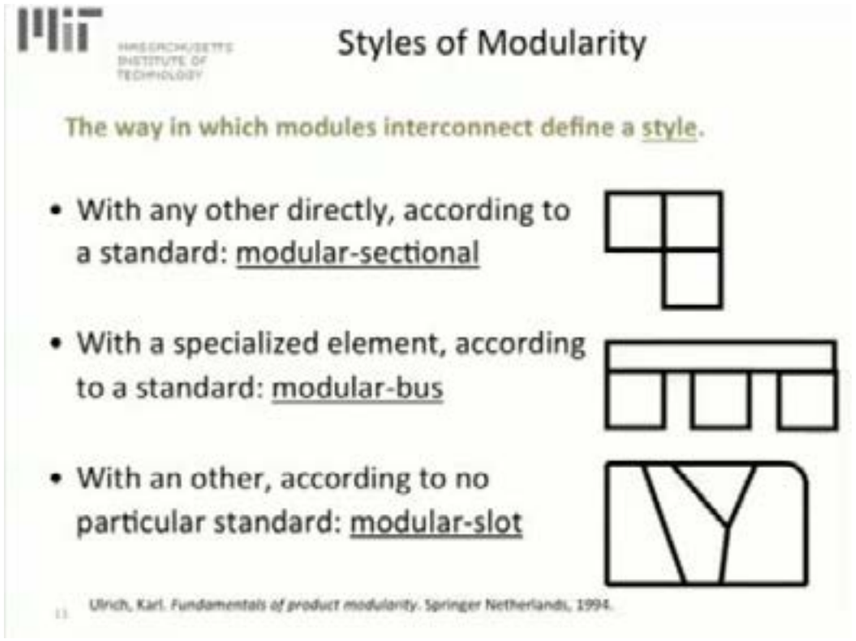
Modularity

In 1991, **Ulrich and Tung**, wrote one of the first papers about modular design. They discussed **two** characteristics of product design:

1. Similarity between the physical and functional architecture of the design

2. Minimisation of incidental interactions between physical components

In 1995, Ulrich extended this work with the thesis that a modular product or sub-assembly has “a one-to one mapping from functional elements in the function structure to the physical components of the product.” [1]



Visual presentation of Karl Ulrich explaining the different styles of modularity
Source: http://www.modularphonesforum.com/news/what-is-modularity-styles-of-modularity-benefits-of-modularity-model-of-the-two-sided-ara-market-343/

1 Ulrich, K. (1995), “The Role Of Product Architecture In The Manufacturing Firm,” Research Policy 24, Elsevier Science B.V.

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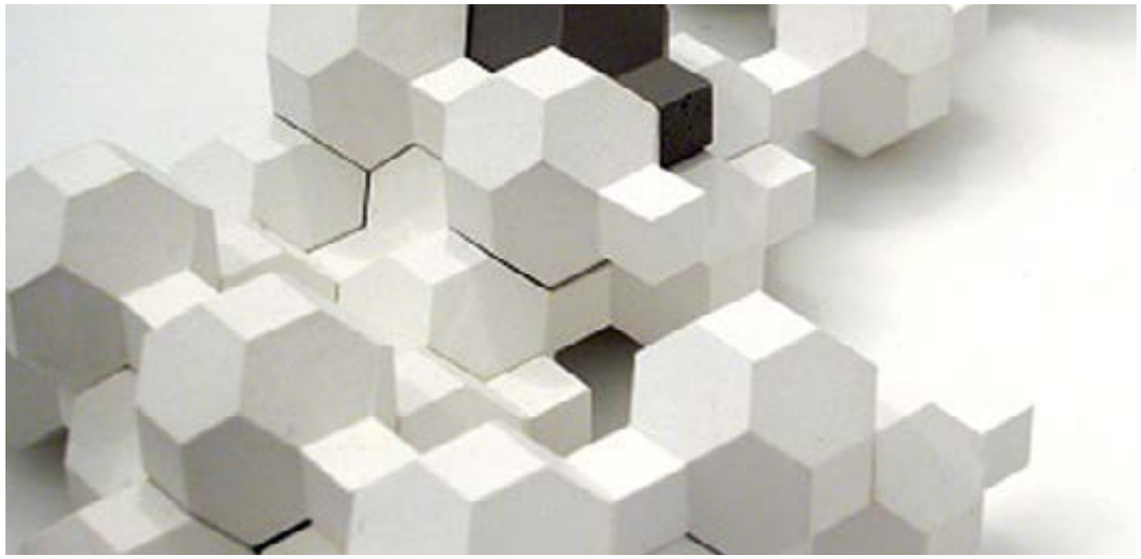

Octogones as modular elements
Source: https://vida.fundaciontelefonica.com/en/project/chapter-ii-understanding-modularity/

Modularity

3.4. Computer-optimised modularity

The point of this paper is not only to talk about the need of modularity in product design but also the need of working with modern techniques to optimise the design process and achieve satisfying results.
Designers today can profit of so called CAD or CAE programs to form and calculate their projects. CAD programs are usually used to construct the form of an object and set it in a virtual context to get an impression of how the final product would appear. CAE programs help to shorten the design and manufacturing process in calculating forces and balancing errors.
It's important not to forget that CAD or CAE programs aren't causing modularity! If an object is modular it's because the designer concepted it to be and not because a programs tells him to do so. Nevertheless it's important to keep up-to-date with the newest technological advances to provide dedicated solutions for objects.
Still those programs are known to be used in the context of engineering though the trend nowadays leans more and more towards furniture design and objects of the all-day context (like tools).
Summed up computer-optimised design is an affiliation of several different programs. CAD programs (for example Rhinoceros) help concepting the object itself and it's function. Furthermore it's possible to render the outcome and set it in a particular space context. In addition Adobe Photoshop can be used to improve visual effects (examples see ff.)
CAE programs on the other hand are used for excluding uncertainties. They analyse the object, calculate the operating forces and consequently optimise the mechanical issues.

CAD of a convertible table by MASISA
Source: http://dornob.com/modular-convertible-chairs-table-storage-furniture-set/

Modular office furniture
Source: http://furniture-pellet-pellets-pallet-palle.blogspot.fr/2012/05/design-elixirboxetti-modular-furniture.html

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Rendering of a modular element designed my Krisztian Griz
Source: http://www.tuvie.com/modular-furniture-design-by-krisztian-griz/

The modual cube
Source: http://vurni.com/restyle-modular-furniture/

Modularity

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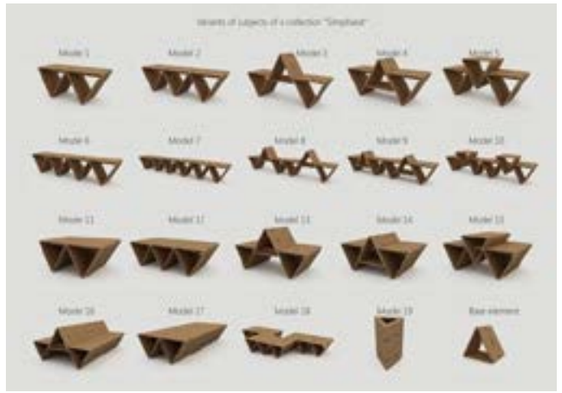
Renderings of space saving and modular room concepts by Tetran
Source: http://designlike.com/limitless-designs-with-the-latest-modular-furniture-concept-from-tetran/

Modularity



Simpliseat from Maksim Shniak
Source: http://materialicious.com/2011/01/simpli-seat-modular-furniture-collection-for-public-area.html

Modular sofa
Source: http://www.tuvie.com/homebox-modular-apart-ment-with-modular-furnitures/

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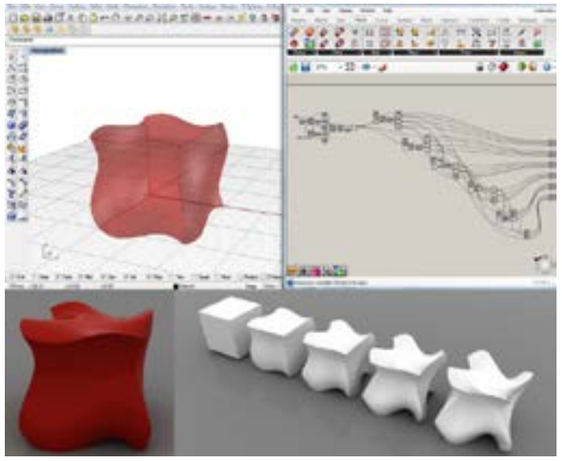
Cubox - modular piece that can be used as storage, buffet or both
Source: http://vurni.com/cubox/

Computer-aided Design

4.1. Overview

Computer systems used to aid in creation are called CAD (Computer-aided design). They help to modify, analyse and optimise design. Those softwares increase the productivity of the designer and the quality of the objects itself. They created a database for manufacturing and therefore improve the communication through documentation.[1] The output comes in form of electronic files for print, machining or manufacturing operations and hence it must contain all necessary informations, such as materials, processes, dimensions and tolerances according to application-specific conventions.



Experimentation with modularity on a cube; Changing the forms with Grasshopper
Source: https://fr.pinterest.com/pin/530228556104971806/

CAD rendering of the Crestapack; a multifunctional and modular tracking backpack
Source: http://johannesjank.com/portfolio/crestapack/

1 Narayan, K. Lalit (2008). Computer Aided Design and Manufacturing. New Delhi: Prentice Hall of India. p. 3 - 4

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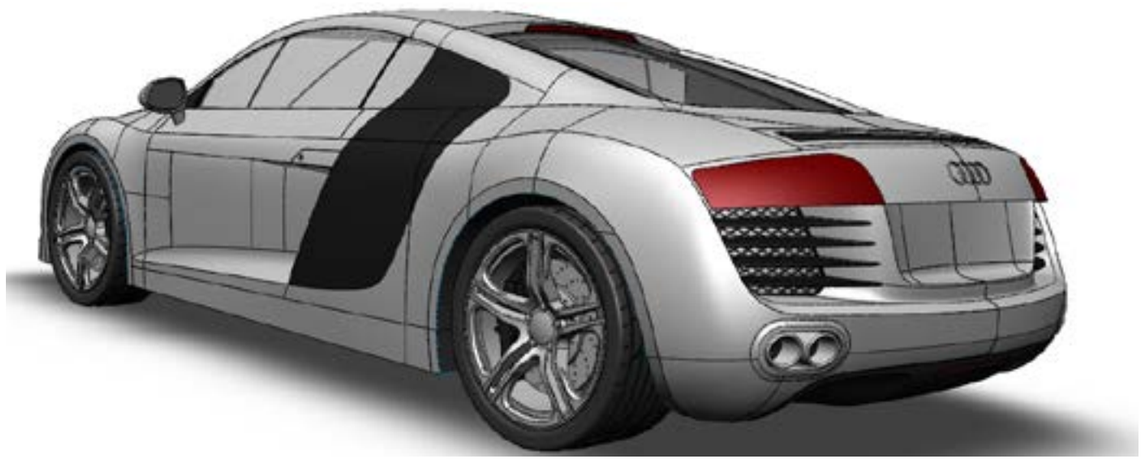
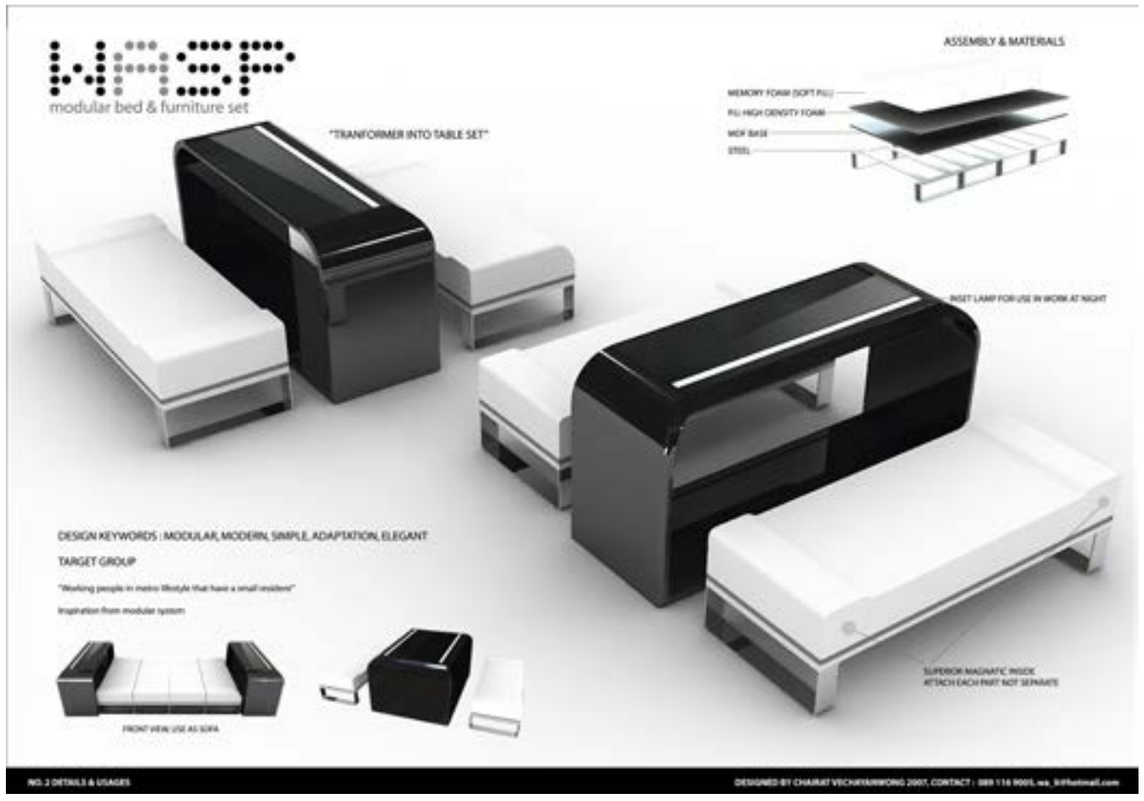
The consequence of the versalility of CAD comes to the fore in all the different fields of it's use. Besides industrial design and architecture, CAD is also used in medecine (Prosthetics i.e.), the car industry, shipbuilding, aeroscience and many more.
Computer aided systems provide more capability than just the ability to reproduce manual drafting with electronic ones. Companies realized quickly that the cost benefit a CAD program supplys can be a determining factor. Not only can they calculate the costs of material or auto layout in integrated circuits, they also give the possibility of interference checking, which stands for excluding errors before the manufacturing.

3D printed titanium leg prosthesis by William Root.
Source: http://microfabricator.com

Computer-aided Design



Sketch rendering of an Audi in Solidworks
Source: http://www.solidsmack.com/resources/how-to-model-a-audi-r8-car-in-solidworks-youll-love-this-video/



Modular bed by Chairat V - modeling in Rhinoceros; rendering in Vray
Source: https://theneteconomy.wordpress.com/2011/12/19/3d-cad-brings-battleships-to-life/

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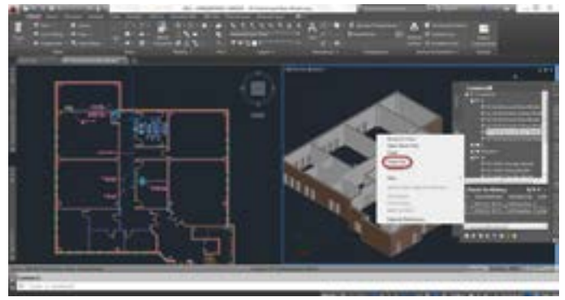
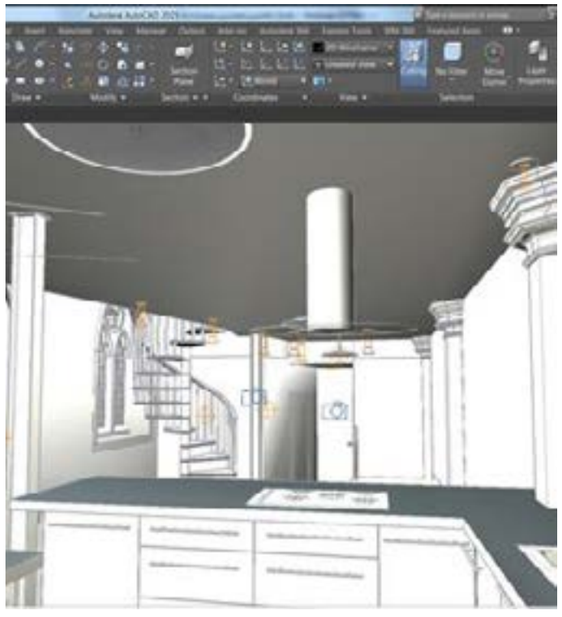
Innovation not only emerges from ideas but also from technologie. Regarding our growing population and the resulting decreasing living space the designer of today must think further. One object can not only stay one object. It has to provide differents possibilities of use and interaction. To achieve the requested abilities, systems have to be invented.
Those systems can result of the forseen material and the function of the object. Therefore not every material promises the maximum use an object shall provide. In former times manual tools, like models were effective. Of course still nowadays a designer can't avoid building models to fulfill his intention, although CAD programs already smooth the way and save time because less manual experiments need to be done.

CAD model in DomusCad for exterieur architecture
Source: http://blog.strategyzer.com/posts/2014/8/18/the-future-of-strategy-and-innovation



CAD model in AutoCad for exterieur architecture
Source: http://www.autodesk.de/products/autocad-architecture/features/all/gallery-view



Rendering of an interior space in Autodesk Maya
Source: https://de.pinterest.com/pin/325244404318281034/

3D model in AutoCAD& renderd in 3D MAX
Source: http://www.coroflot.com/3esolutions/Rendering-Architecture-CAD

Computer-aided Design

Eventually CAD provides the designer with the ability to perform engineering calculations.
Before CAD programs were a common tool for a designer, those calculations had to be performed by specialists. Thus we can say that CAD was a revolutionary change in the engineering industry, where draftsmen, designers and engineering roles begin to merge.
Current computer-aided design software packages range from 2D vector-based drafting systems to 3D solid and surface modelers. Modern CAD packages can also frequently allow rotations in three dimensions, allowing viewing of a designed object from any desired angle, even from the inside looking out.

The Bunkie kit contains 15 large pieces of structural plywood, which were designed using CAD modeling. The structure can be manufactured and assembled like a piece of modular furniture.
Source: http://www.tinyhousecommunity.com/map/0929-preassembled-small-cottage-kit-the-bunkie-doesnt-need-building-permit/

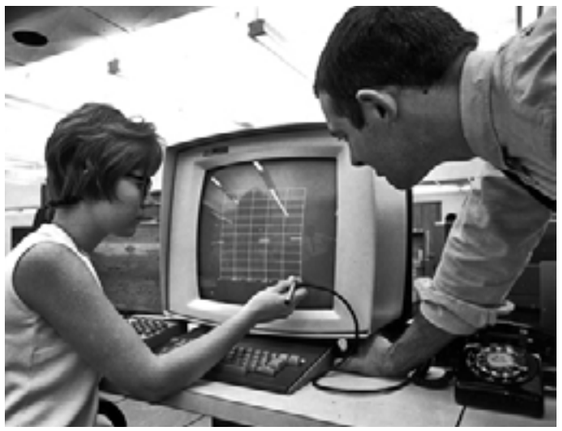
Modular furniture for kids. Mod.U.Me by Yana Tzanov
Source: http://www.coroflot.com/yanatzanov/ModUMe

Computer-aided Design

4.2 Historical Context

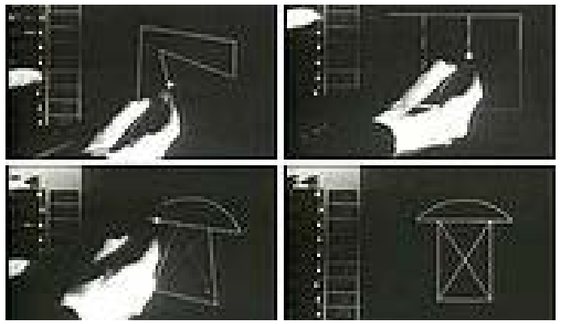
In the middle of the 20th century the term CAD (Computer-aided Design) was first used by the american computer scientist **Douglas Taylor**, developer of APT (Automatically Programmed Tools) and chairman of Softech.Inc.[1] Until the late 1950s designers were already using certain algebraic, symbolic and often vector-based computer programs to optimise their calculations. Those graphic mathematical processes of forming a shape with a digital machine tool were surely innovative and uncommon, nevertheless necessary for the modern designer.

Computer Aided Design of Integrated Circuits (CADIC) 1967
Source: http://engineeringhistory.tumblr.com/image/63372513153



IBM 360/67 mainframe-powered CAD system at Fairchild in 1967
Source: http://www.computerhistory.org/siliconengine/computer-aided-design-tools-developed-for-ics/

1 Nigel Horspool (2007). “Douglas T. Ross (1929–2007)”. In: Source Software—Practice & Experience archive. Vol 37, 7, p. 691

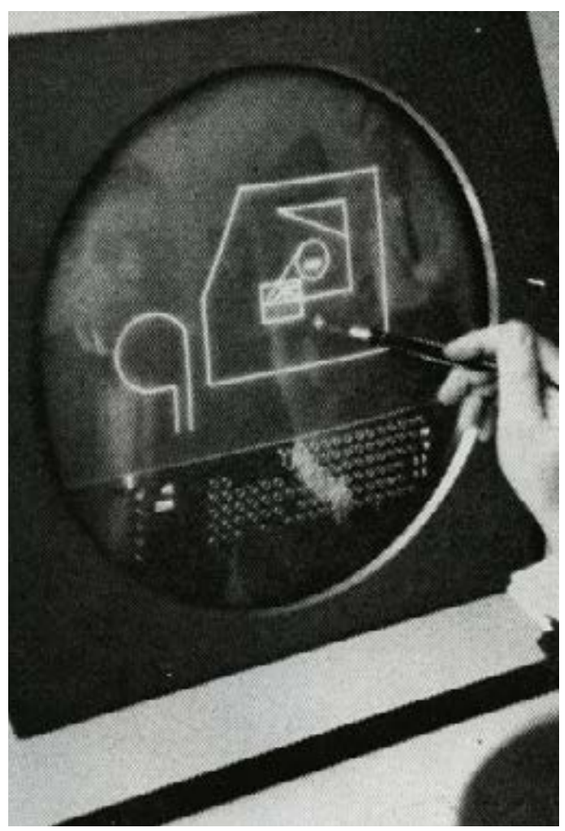


Ivan Sutherland demonstrating Sketchpad
Source: https://en.wikipedia.org/wiki/Sketchpad

With the invention of “Unisurf” the French engineer, **Pierre Bezier** (Arts et Métiers ParisTech, Renault) set the milestone to 3D CAD/CAM between 1966 and 1968. However in 1963 a system called “Sketchpad” smoothed the way for Bezier’s invention. **Ivan Sutherland** conceived a program which allowed the designer to interact with his computer graphically by drawing on a CRT (Cathode Ray Tube) monitor with a light pen. Effectively, it was a prototype of graphical user interface, an indispensable feature of modern CAD.[1] With the invention of CAD it now was possible to create electronic symbols and geometric figures. An object once drawn could be reproduced or changed in orientation and scale. At the early beginning of using CAD the designer was still limited in its use although it suggested numerous possibilities.

1 Lincoln Laboratory Journal 19”Looking Back: The TX-2 Computer and Sketchpad 82”

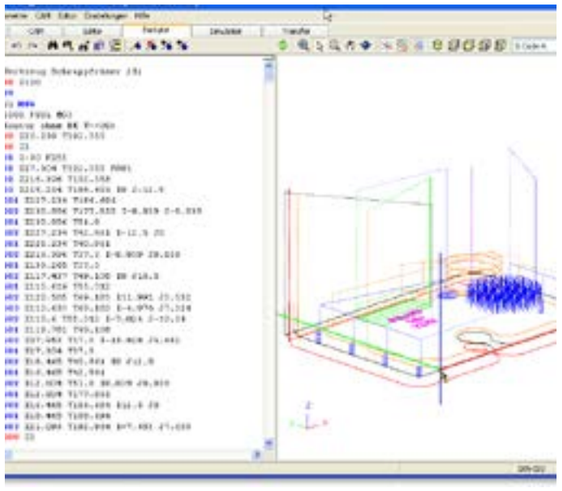
Sketchpad by Ivan Sutherland 1963
Source: https://de.pinterest.com/pin/268316090274825331/



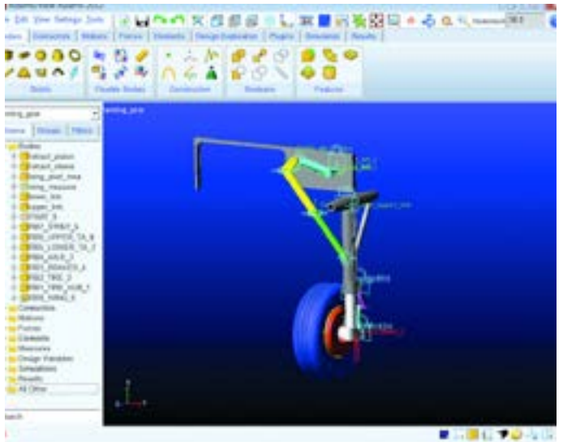
Source: http://blog.grabcad.com/blog/2013/06/13/the-hardware-of-cad/

Computer-aided Design

Ten years of interdisciplinary development work from the MIT's lab enabled the path of modern CAD programs.[1]
Within the aircraft, automotive, industrial control and electronics industrie further developments in 3D surface construction, NC programming (numerical control) and design analysis were educed. They were independent of one another and often published much later than discovered.
The founding of MCS (Manufacturing and Consulting Services Inc.) in 1971 by Dr. P.J. Hanratty who wrote the system ADAM (Automated Drafting and Machining) was one of the most influential events in the development of CAD.[2]
In the beginning only big companies were supplied as the computer technologie was still not affordable to everybody.



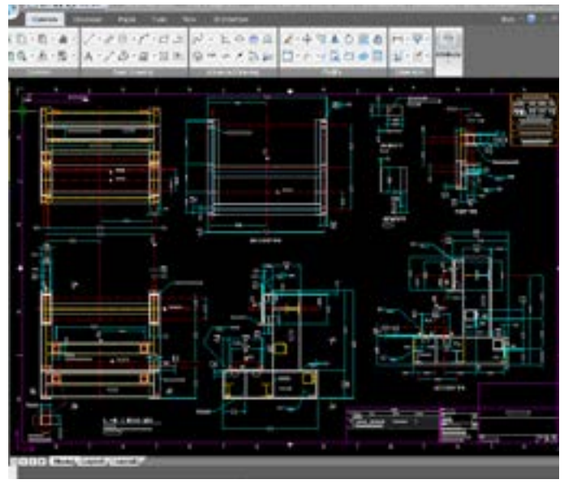
Filou NC. NC program.
Source: http://cnc-step.de/produkte/software



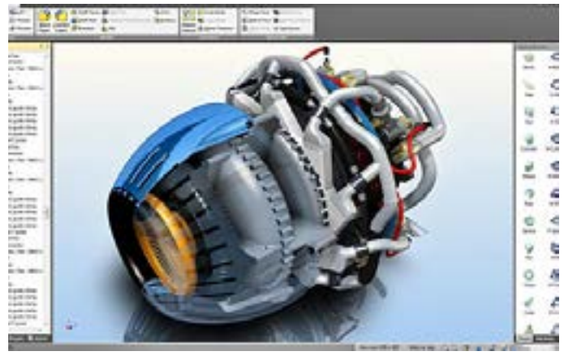
Example for ADAM (version from 2012)
Source: http://www.mscsoftware.com/product/adams

1 Lincoln Writer, ScopewriterWeisberg, David E. The Engineering Design Revolution, p.3 ff
2 "MCS Founder: Patrick J. Hanratty, Ph.D., President and Founder"; http://web.archive.org/web/20050209155207/http://mcsaz.com/about/founder.htm

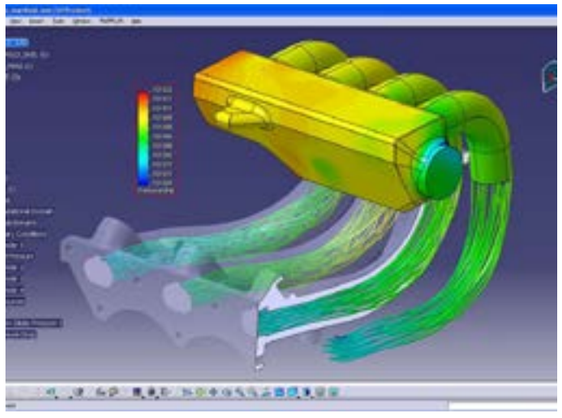
In the 1970s, 3D drawings were limited to producing similar sketches to hand-drafted ones. Notable soild modeling began in the 1980s.
Key products for 1981 were the solid modelling packages "Romulus" (ShapeData), "Uni-Solid" (Unigraphics) and the release of the surface modeler CATIA (Dassault Systemes).
Autodesk was founded 1982 by John Walker, which led to the 2D system AutoCAD.
In 1987 "Pro/Engineer" was released, which provided a greater usage of feature-based modeling methods and parametric linking of the parameters of features. The development of the B-rep solid modeling kernels took CAD programs a step further to the future. B-rep means boundary representation and is a method of representing shapes using limits or rather a method showing the boundry between solid and non-solid.
The significant results of this inventions were "Solidworks" and "TriSpective" (later know as Ironcad) in 1995



2D circuit diagram of an engine in Ironcad
Source: http://www.ironcad.com/index.php/products/ironcad



3D model of an aircraft turbine in ironcad
Source: http://www.ironcad.com/index.php/products/ironcad



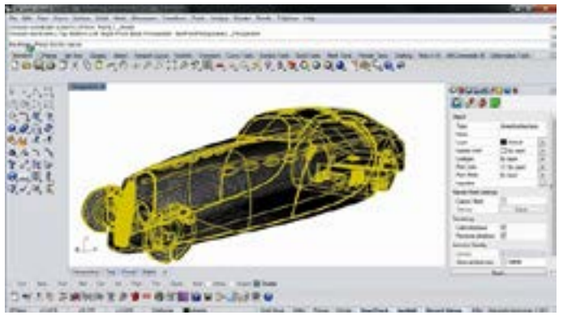
Example for CATIA.
Source: https://www.mentor.com

Computer-aided Design

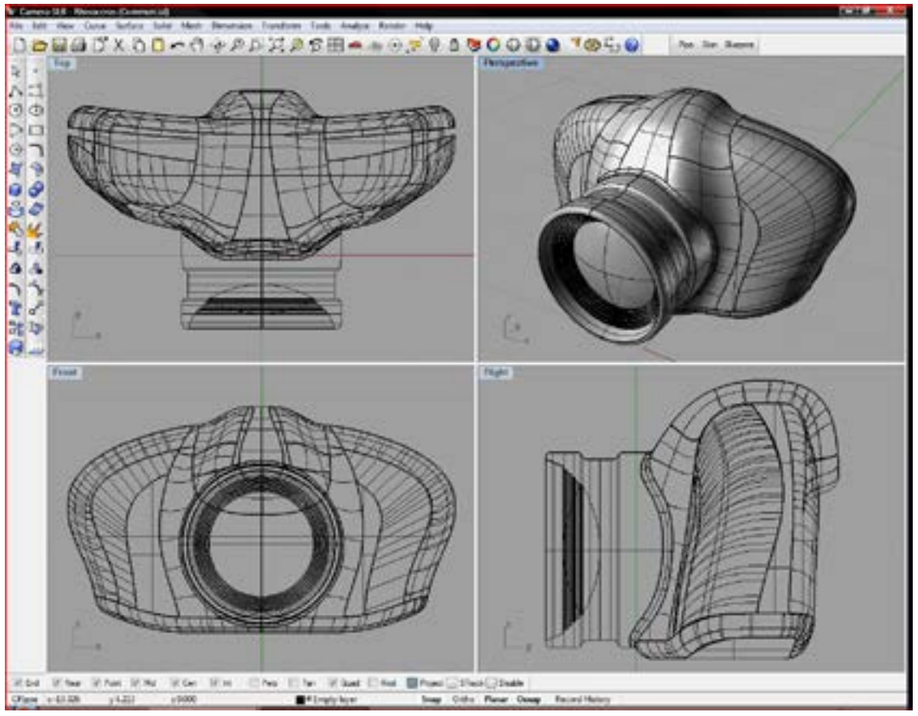
4.3. CAD

4.3.1. Rhinoceros and Grasshopper

Rhinoceros is a commercial 3D computer graphics and CAD application software developed by Robert McNeel & Associates, found in 1980. Rhino is based on the NURBS (non-uniform rational basis spline) mathematical model. Mathematically precise representation of curves and freeform surfaces are the focus.
Rhinoceros is used in processes of computer-aided design (CAD), computer-aided manufacturing (CAM), rapid prototyping, 3D printing and reverse engineering in industries including architecture, industrial design, multimedia and graphic design.

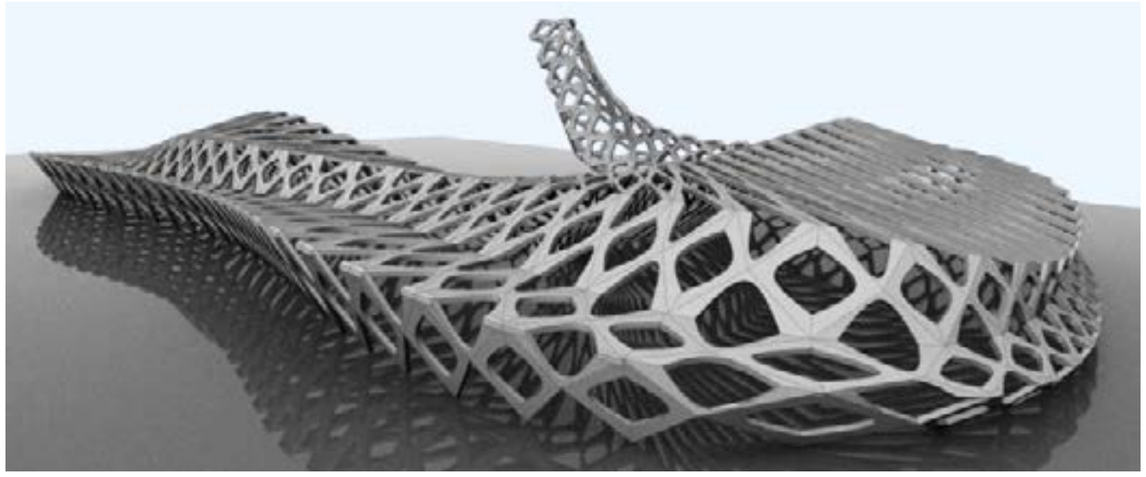


Seeing the structures. An old timer modeled in Rhinoceros 3d in 1:100 for 3D printing
Source: https://i.materialise.com/blog/3d-printing-with-rhino/



Example for the interface in Rhinoceros3d: Camera construcion
Source: http://www.3dprinter.net/rhino-3d-review

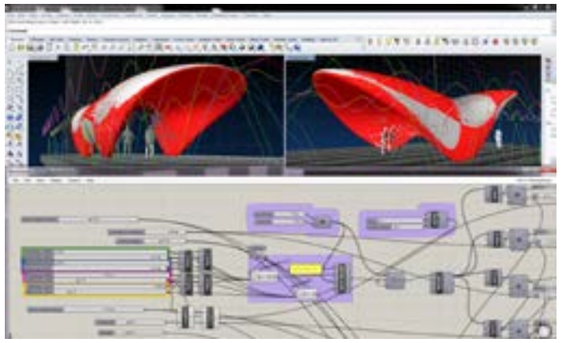
Rhinoceros may be understood as a free form surface modeler, that means every shape is possbile to generate. Also there are loads of plug-ins available that complement and expand Rhino in specific fields like rendering and animation.
The file Rhinoceros data is exported is .3dm but it also provides compatability in import and export with over 30 other CAD file formats.
Furthermore Rhino is compatible with a number of graphic design programs like Adobe Illustrator which in this context is mostly used vector based.



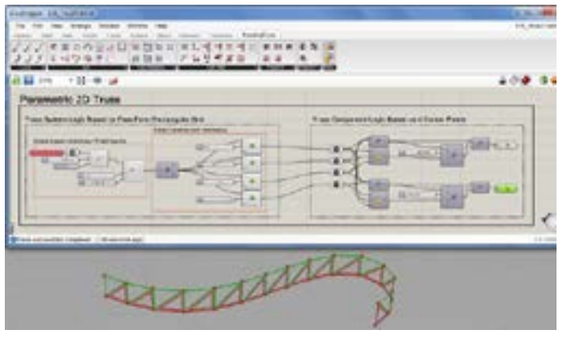
Rendering of a modular comb structure in Grasshopper
Source: http://www.rhino3dmexico.com/productos/grasshopper.html

Computer-aided Design

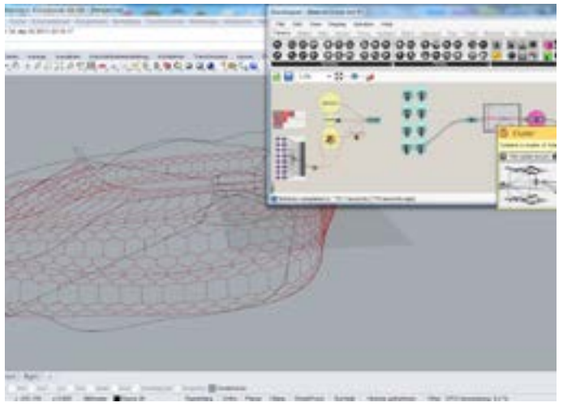
Besides Rhinoceros supports two scripting languages, Rhinoscript (based on VBScript) and Python (V5.0+ and Mac). It also has an SDK (software developing kit), and a complete plug-in system.
One McNeel plug-in, a parametric modeling/visual programming tool called Grasshopper, has attracted many architects to Rhinoceros due to its ease of use and ability to create complex algorithmic structures.
Grasshopper is a visual programming language also developed by Robert McNeel and Associates and David Hutten. The program is created by dragging components onto a canvas. The outputs to these components are then connected to the inputs of subsequent components.
It is primarly used to build generative algorithms. Grasshopper's components mostly create 3D geometry patterns but connected programs may also contain other types of algorithms including numeric, textual, audio-visual and haptic applications.[1]



Model of a bustop in Grasshopper. The roof is meant to be modular in the sense of addition and subtraction
Source: http://petersandhaus.blogspot.fr/?view=classic



Example for parametrics in Grasshopper
Source: http://blog.de.rhino3d.com/2012_04_01_archive.html



Parametric structure of leather. Modeled in Rhino added in Grasshopper with parametrics.
Source: http://www.alan-shapiro.com/material-grove-3-d-modeling

1 Andrew, Kudless (July 2011). "Biodigital Architecture Master". Biodynamic Structures Workshop. California College of the Arts, San Francisco: AA San Francisco Visiting School. Retrieved Feb 9, 2011.

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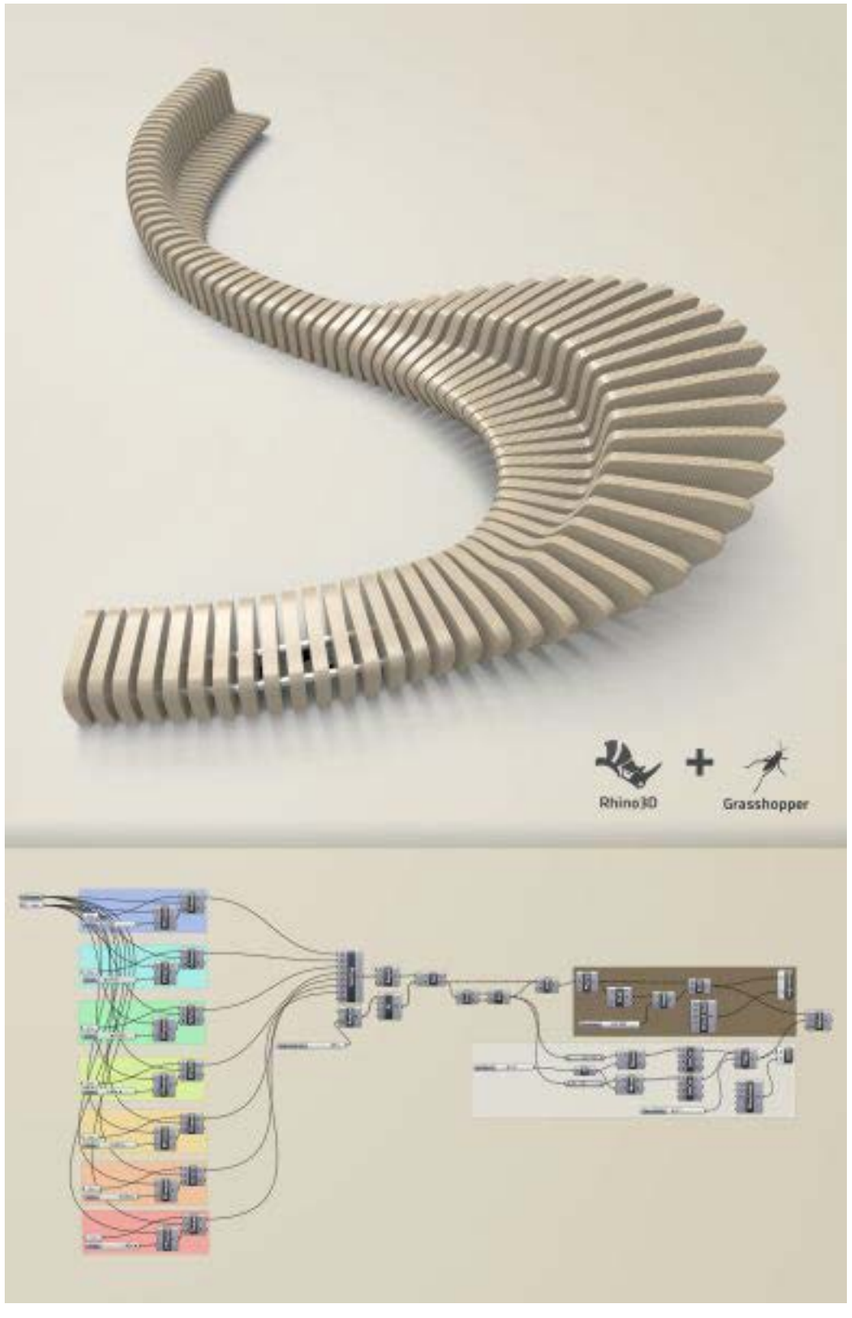
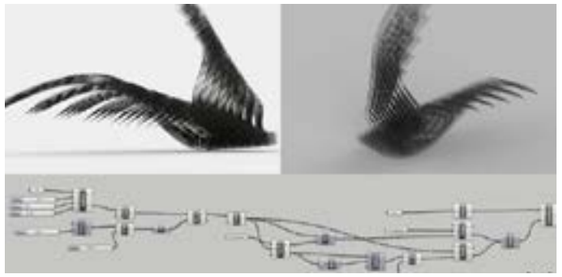


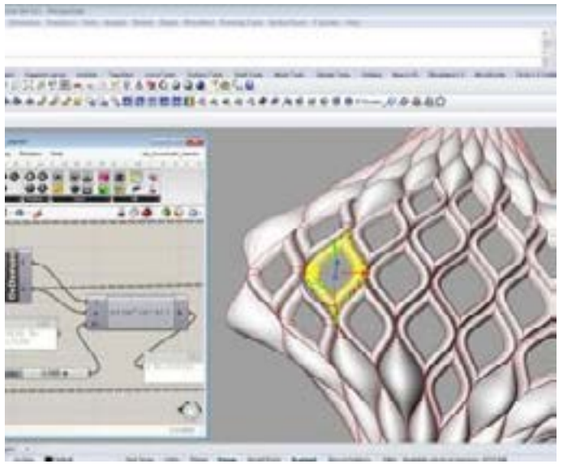
Modeling in Grasshopper of a modular bench
Souce: https://fr.pinterest.com/source/grasshopper3d.com

Computer-aided Design

The interface is kept minimal as Grasshopper is a plug-in of Rhinoceros so it mostly consits the components of “palettes” and “canvas”.
The Node-based editor is the most important part of the interface. The data is passed from component to component via connecting wires which connect an output and an input grip. It can either be defined locally as a constant or being imported from a Rhinoceros file. The data is always stored in parameters which can be free-floating or attached to a component as an input/output object.
Summed up Rhinoceros or Grasshopper are the first steps in the CAD design process. Depending on the habit of the designer Autocad or Solidworks will do as well. In general those programs transform the idea on paper into a virtuel draft. A good knowledge of CAD can help skipping several steps in the design process. No need of tryout models for example. The idea is techincally already on the way to be realized as a 3D model when put into a CAD program.

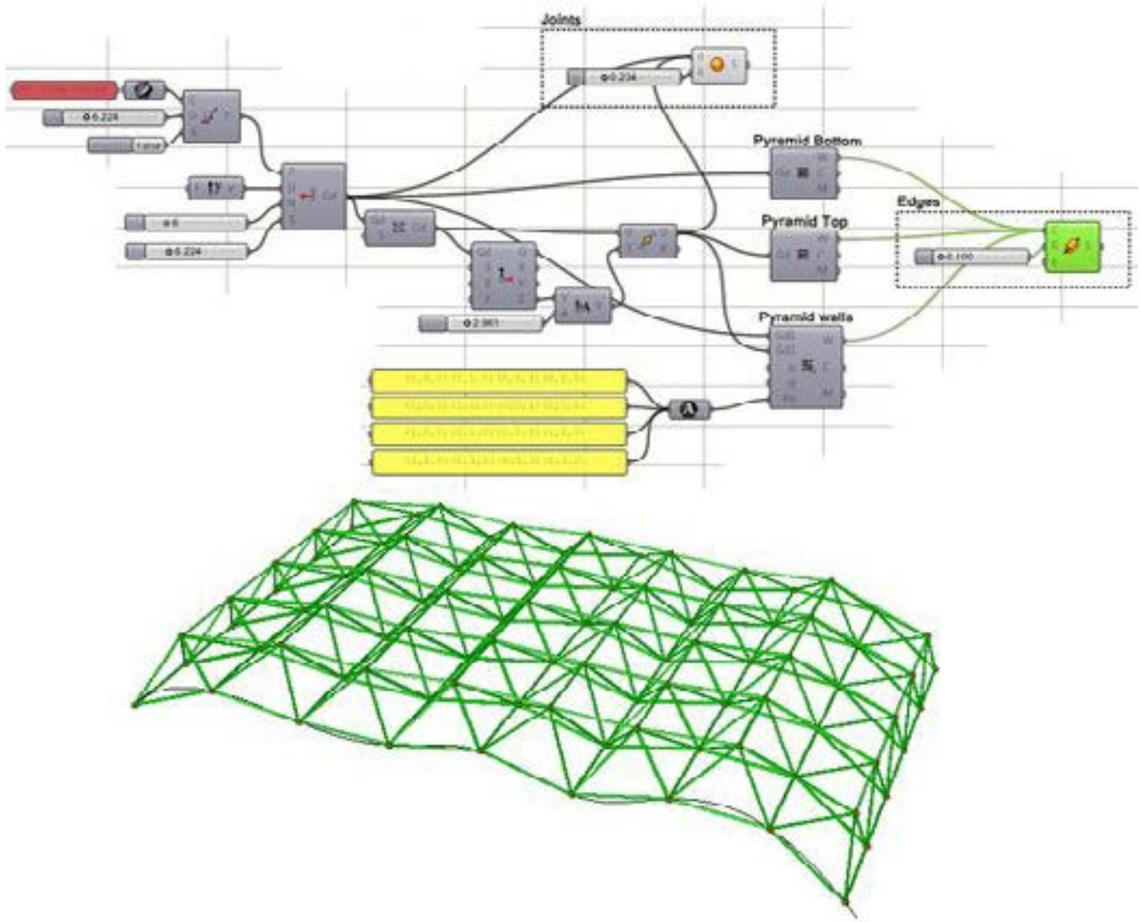


Parametic definition
Source: http://www.coroflot.com/ky_snyder/public-folio



Experimentation with forms
Source: http://designalyze.com/tutorial/swapping-geometry-using-thresholds

3D printed parametic curtain wall made with Grasshopper
Source: http://www.thingiverse.com/thing:119598



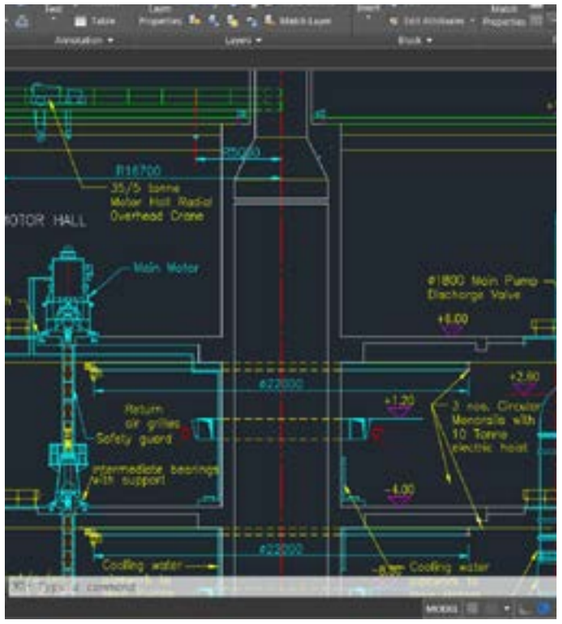
Paneltool in Grasshopper. Example for the interface.
Source: http://blog.fr.rhino3d.com/2012/04/tutoriel-de-creation-de-treillis.html

Computer-aided Design

4.3. CAD

4.3.2. Autocad

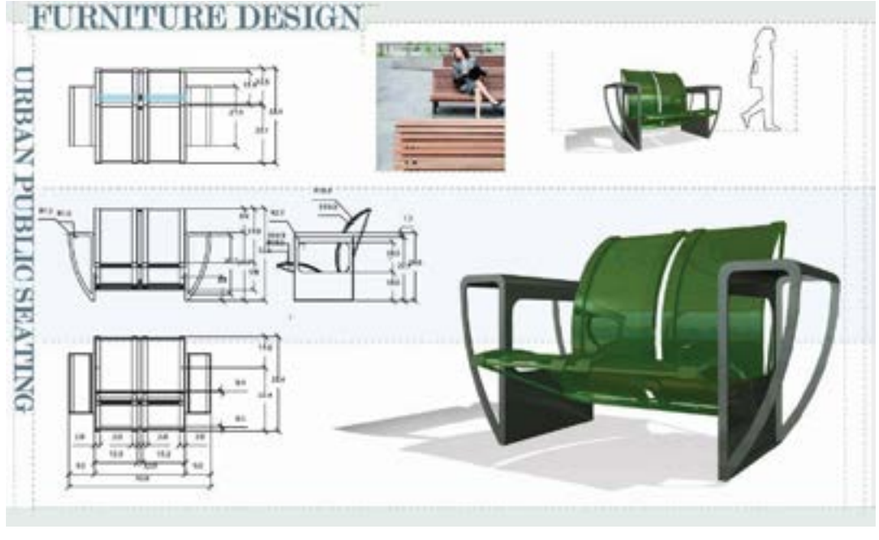
AutoCAD is a commercial software application for 2D and 3D CAD drafting. Found in 1982 as a desktop application and since 2010 as a mobile, web- and cloud-based app marketed as Auto-CAD 360.
The forerunner of Autocad was Autodesk.
Autocad first released in 1982 running on microcomputers with internal graphics controllers was revolutionising the CAD market. Most commercial CAD programs at that time were running on mainframe computers or minicomputers with each CAD operator working as a seperate graphics terminal. [1]
Autocad is used across a wide range of industries, by architects, project managers, engineers, graphic designers, and other professionals. It is supported by 750 training centers worldwide as of 1994.[2]
The native file format of AutoCAD is .dwg.
Furthermore there are serveral compatible files for Autocad as well like ESRI Arc Map 10 or LandXML. Additionally there are certain third-party file converters but also pdf files are feasible, however the result of the exported file might be unpredictable or distorted.
Autocad also supports a number of APIs (application programming interface) for customisation and automation like AutoLISP, VisualLISP, VBA, .NET and ObjectARX.



Autodesk/ Autocad 2D detail of an engine
Source: http://www.mycomputersmith.com/autocad/

1 http://cadhistory.net/02%20Brief%20Overview.pdf
2 http://www.fundinguniverse.com/company-histories/autodesk-inc-history/

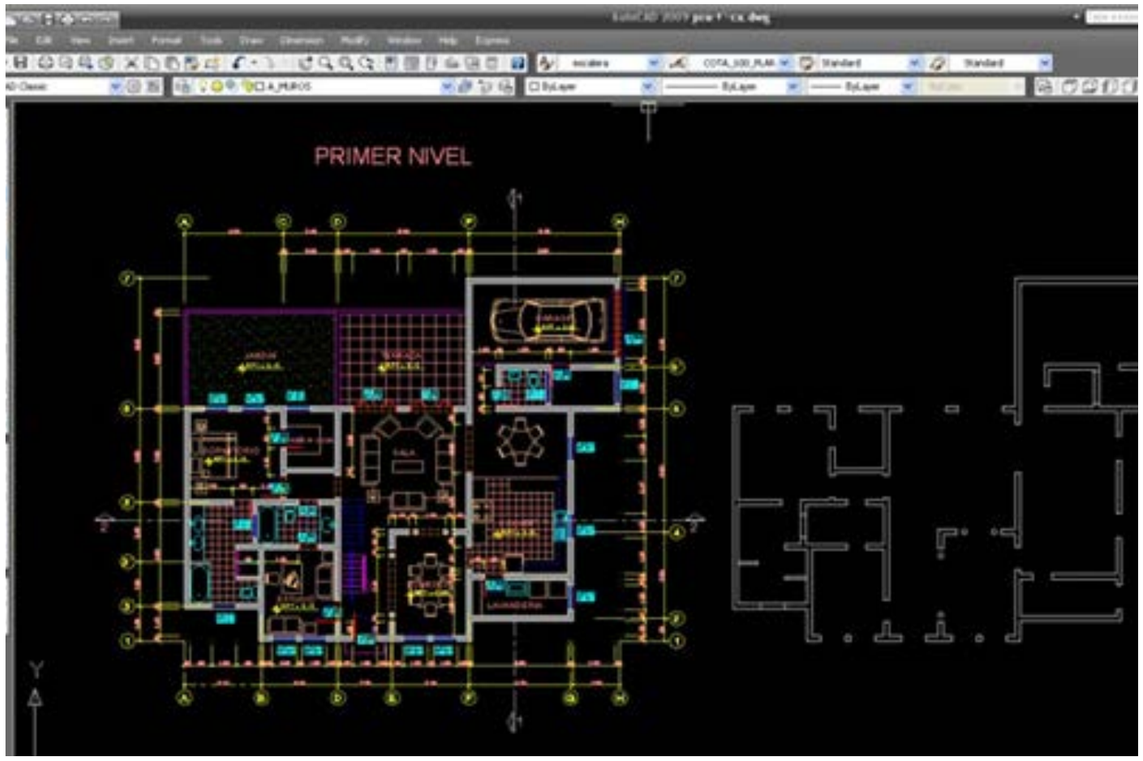
Cantilever desk concept modeled in Autocad
Source: http://www.coroflot.com/traviscoe/Furniture-Design



Armchair modeled in Autocad
Source: http://www.coroflot.com/traviscoe/Furniture-Design

Computer-aided Design

The following are example for features in Auto-cad. The aren't modular or space saving, they only shall exemplify the different visualisations.



Conception of a house in Autocad
Source: http://www.archicadbimcenter.com/artikel/Importieren_einer_Datei_in_SketchUp_AutoCAD_-90/ale

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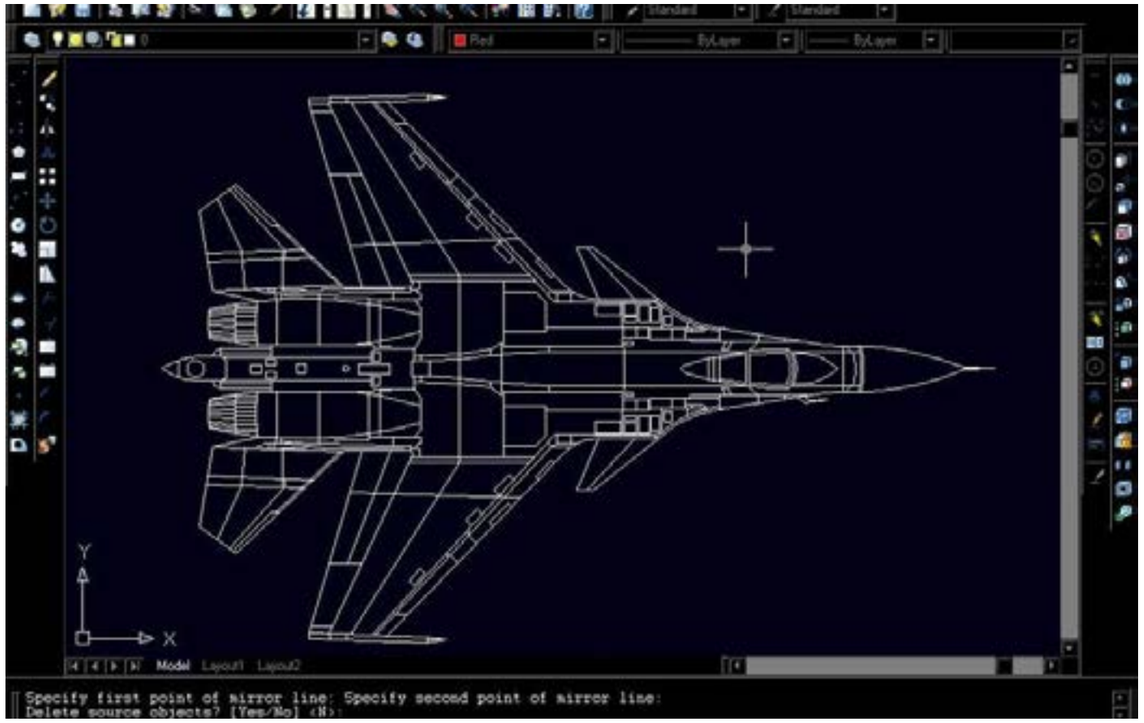
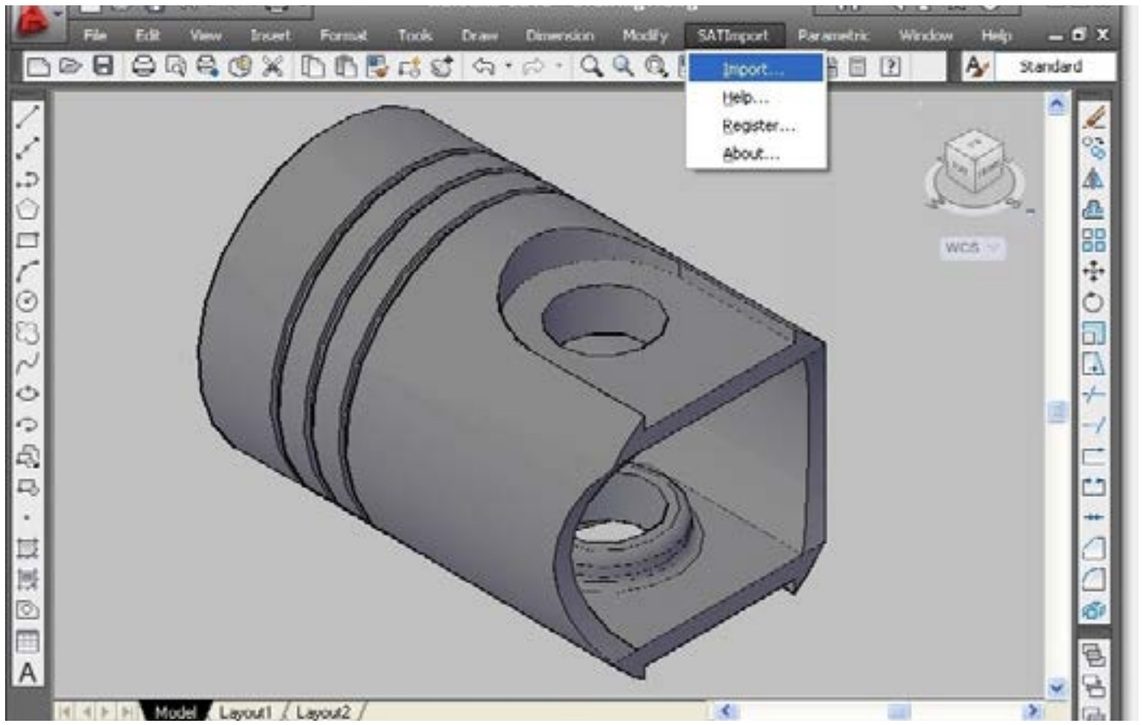


2D plan view in Autocad of a military jet
Source: http://crackedtool.com/autocad-2007-crack/



3D rendering in Autocad
Source: http://getintopc.com/softwares/3d-cad/autocad-2010-free-download/

Computer-aided Design

4.4. CAE

4.4.1 From CAD to CAE

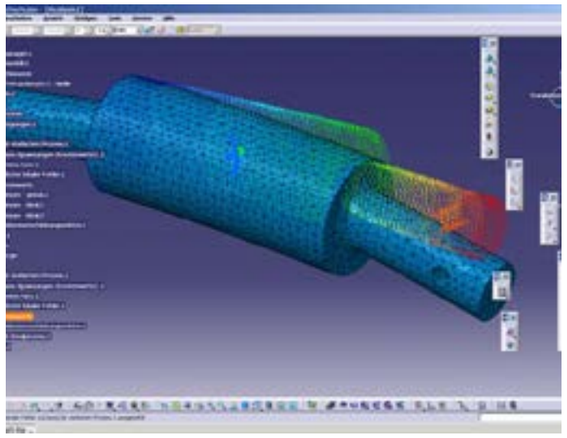
CAE (computer-aided engineering) is the comprehensive usage of software to help in engineering analysis tasks. Compared to CAD the main use of CAE is the engineering part. CAD programs form an object and CAE reappraises the material properties of the surface and recalculates the operating forces.
It includes Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), Multibody dynamics (MBD), and optimization.
CAE is the final step for optimising a product. It is for example possible to analyse the robustness or performance of components and assemblies. Consequently it involves simulation, validation and optimisation of prdoucts and manufacturing tools.
CAE operates in many areas:

Stress analysis using FEA

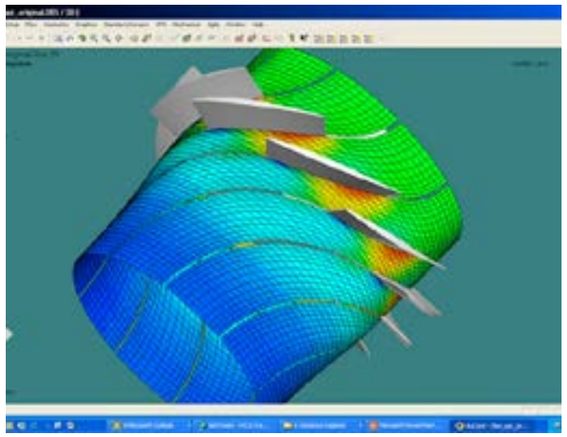
Thermal and fluid flow analysis CFD

Optimisation (product as well as process)

MBD and Kinematics

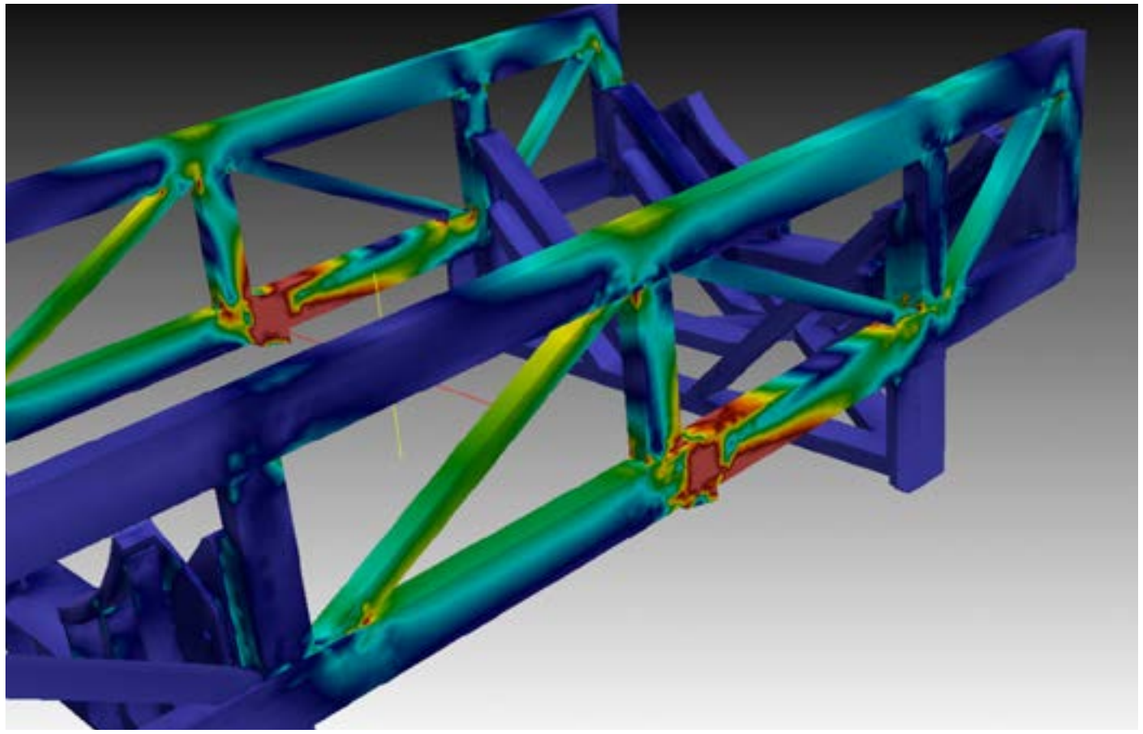


Stress analysis of an axes
Source: https://tu-dresden.de/die_tu_dresden/fakultaeten/fakultaet_maschinenwesen/itm/institut/tech_aus/cae_technik/index_html



Flow field contours superimposed on a CFD computational mesh for an axial compressor
Source: http://www.conceptsnrec.com/Resources/Photo-Gallery/CAE-Software.aspx

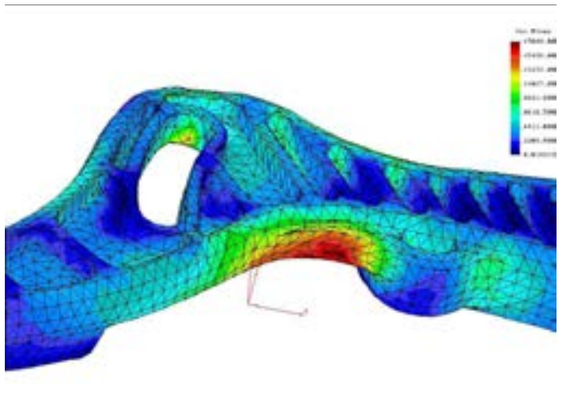
Process simulation means analysing operations such as casting, press forming or molding.
The process of CAE can be understood in 3 phases. Starting with pre-processing which means to find a definition for the model and enviromental factors that apply. The second step is doing the analysis depending on the characteristics of the object and the final step is the visualisation (3D modeling).
Usually for quality control this cycle is repetitive, either manual or with commercial optimisation software.
Most common used programs are ANSYS, Autodesk Simulation, CATIA, Siemens NX and Solidworks.



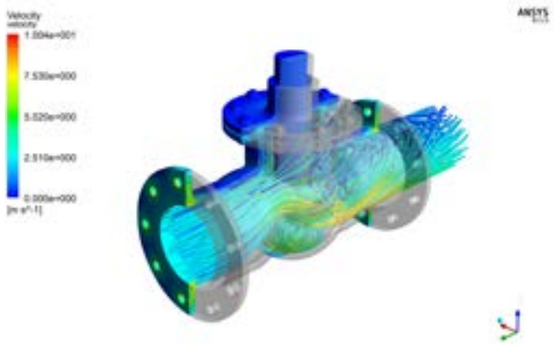
Strength analysis in Fidesys
Source: http://www.cae-fidesys.com/en/products/cae

Computer-aided Design

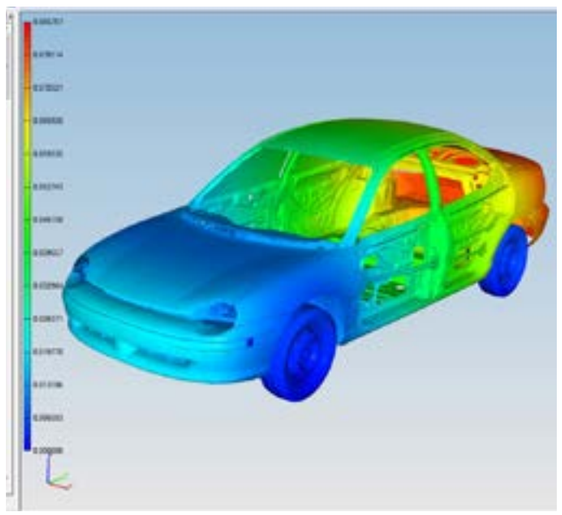
The connection between CAE and modularity is simple. To achieve a well functioning product the use of CAE is inevitable. Especially if an object runs through different stages of usage.
So when the concept of modularity is considered innovation then also the concept of it's manufacturing must be innovative which means the goal must be to minimalise the steps of the design process to a maximum.
Nowadays CAE is still mostly used in the car industry or any other engineering dominated field allthough it is important to understand that for any kind of innnovation and that includes product design as much as ship building, it is becoming more and more essential to use all resources of modern techniques.



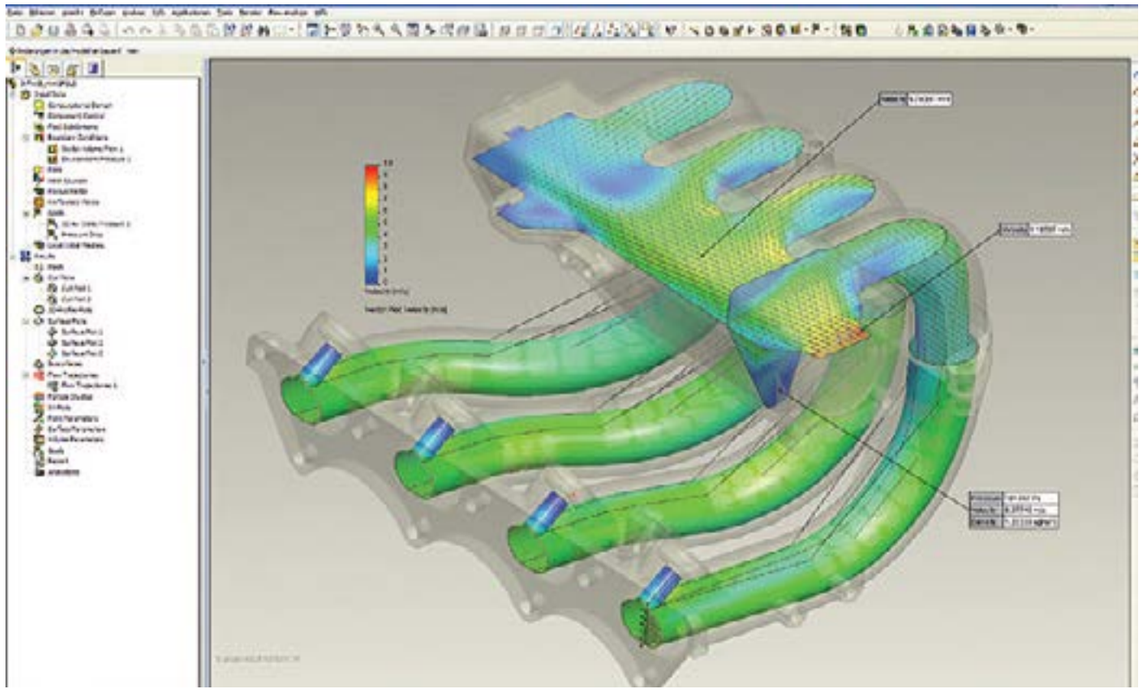
Finite Element analysis
Source: http://www.patriotengineeringco.com/analysis.htm



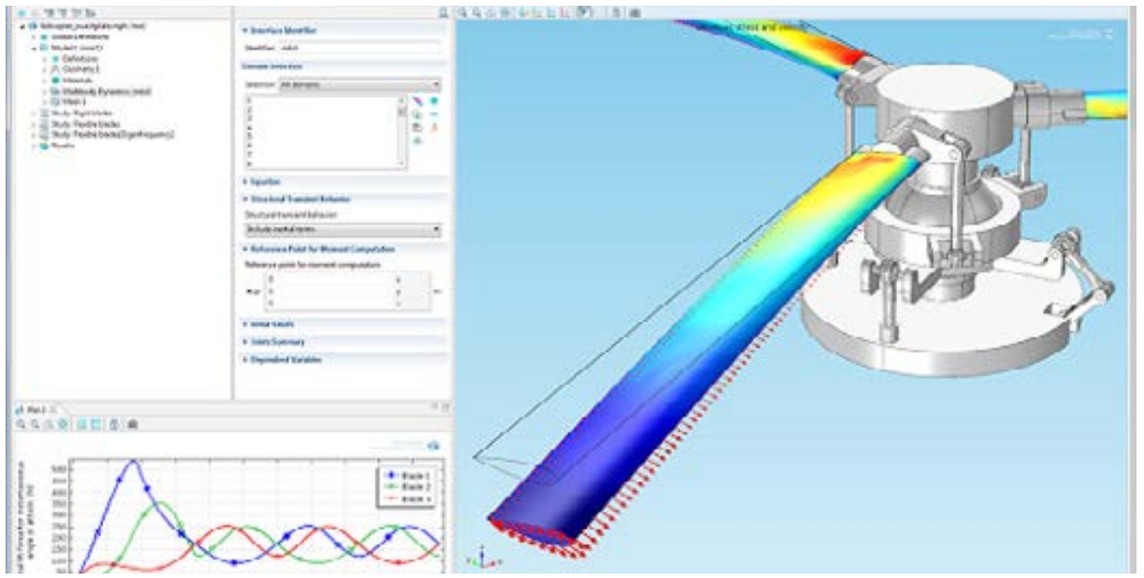
Finite Element analysis of a gas pipe
Source: http://www.tuvnel.com/site2/subpage/software_solutions_finite_element_analysis



Stress analysis of a car
Source: http://www.vcollab.com/News/April-2015/VCollab-announces-solutions-to-convert-CAE-Data-to.html



Computational Fluid Dynamics in a pipe system
Source: http://www.designworldonline.com/5-myths-of-cfd/



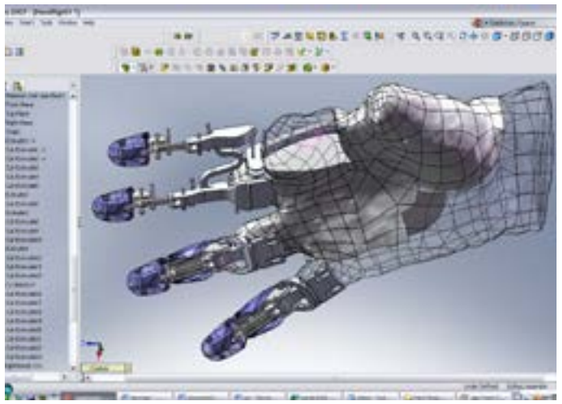
Multibody Dynamics
Source: https://www.comsol.com/blogs/simulate-mechanical-systems-with-the-multibody-dynamics-module/

Computer-aided Design

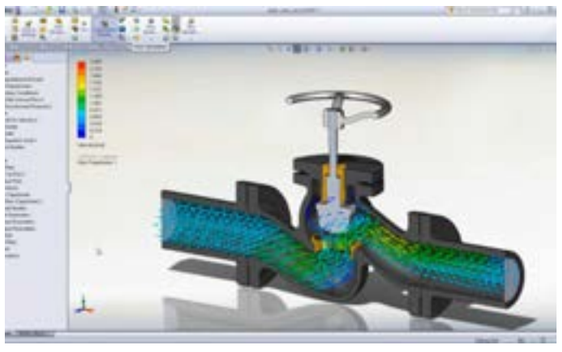
4.4. CAE

4.4.2. Solidworks

Solidworks is a solid modeling CAD and CAE program which means it combines the two and it runs on Microsoft Windows.
The corporation was found in 1993 by John Hirschtick. The idea of Hirschtick was to program a 3D CAD software that was easy to use, affordable and availabe for Windows.[1]
These days Solidworks markets several versions of their CAD software in addition to eDrawings (collaboration tool) and Draftsight (2D CAD).
Solidworks is a solid modeler which means it's a consistent set of principles for mathematical and computer modeling of three-dimensional solids.
It uses parametrics to create models and assemblies. The software is written on a Parasolid-kernel (geometric modeling kernel).



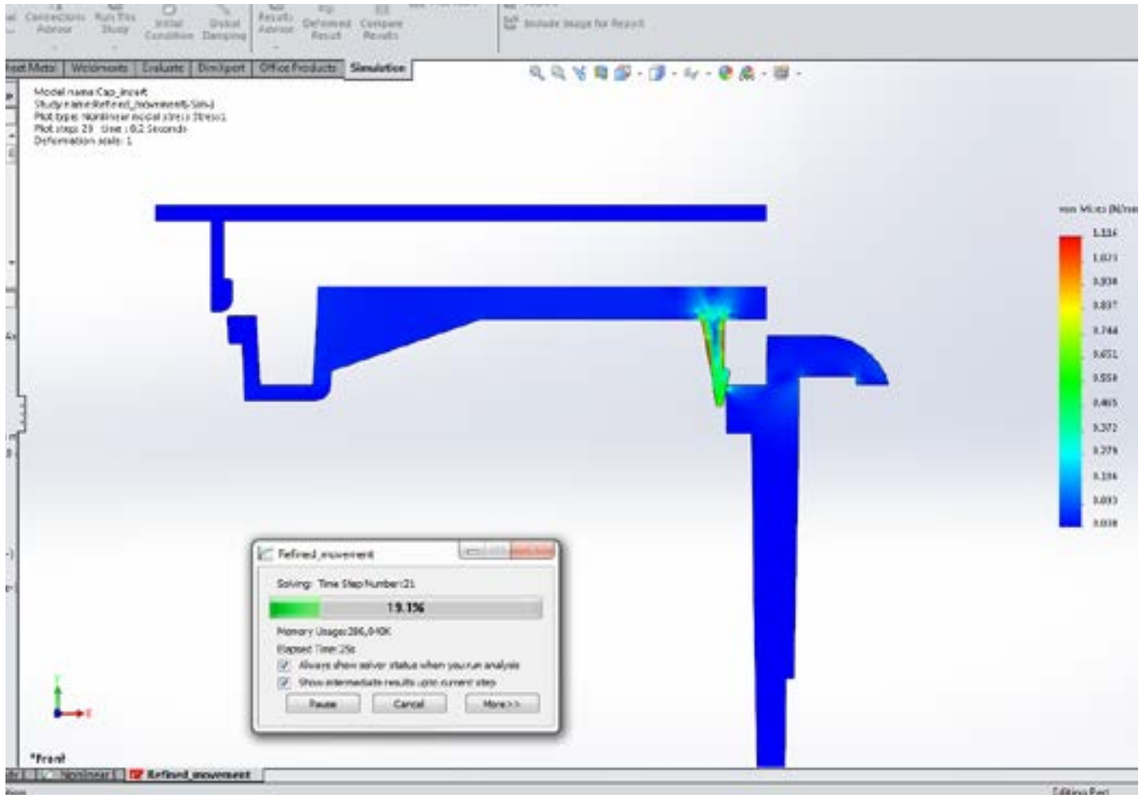
3D modeling of a hand prothesis in Solidworks
Source: https://3dprint.com/44267/xbom-tool-for-solidworks/



Computational Fluid Dynamics in a water pipe made in Solidworks
Source: http://tech-clarity.com/solidworks-vision-2014/3896

1 History of the company. Source: http://www.solidworks.com/sw/656_ENU_HTML.htm

The shape or geomtery of models is determined by the contraints of the parameters which can either be line lenghts, circle diameters or geometric parameters such as tangents, parallels, concentrics, horizontals or verticals etc. Numeric parameters can be associated with each other through the use of relations which allows them to capute design intent.
Design intent is the way the creator of the parts want it to respond to changes and updates.
For example if a beverage is designed in Solidworks with a hole at the top, the hole can stay at the top surface regardless of the height or size of the can.
SolidWorks allows the user to specify that the hole is a feature on the top surface, and will then honor their design intent no matter what height it's later assign to the can.
Shaped-based features usually begin with a 2D or 3D sketch. Operation-based features aren't sketch-based and they include features such as fillets, chamfers, shells, applying draft to the faces of a part etc.



Calculating forces in Solidworks
Source: http://blogs.solidworks.com/solidworksblog/2014/08/sneak-peek-15-features-coming-in-solidworks-2015-incremental-simulation-results.html

Computer-aided Design

A sketch in Solidworks is build of consists of geometries such as points, lines, arcs, conics and splines. After dimensions are added to define the size and location of the geometry, realtions are used to define attributes such as tangency, parallelism, perpendicularity and concentricity. Those dimensions which can be controlled independently and relations drive the geometry not the other way around.
Summed up drawings can be created either from parts or from assemblies. Views are automatically generated from the solid model and notes, dimensions and tolerances can then be easily added to the drawing as needed.
Solidworks files use the Microsoft Structured Storage file format. This means that there are various files embedded within each SLDDRW (drawing files), SLDPRT (part files), SLDASM (assembly files) file, including preview bitmaps and metadata sub-files.[1]

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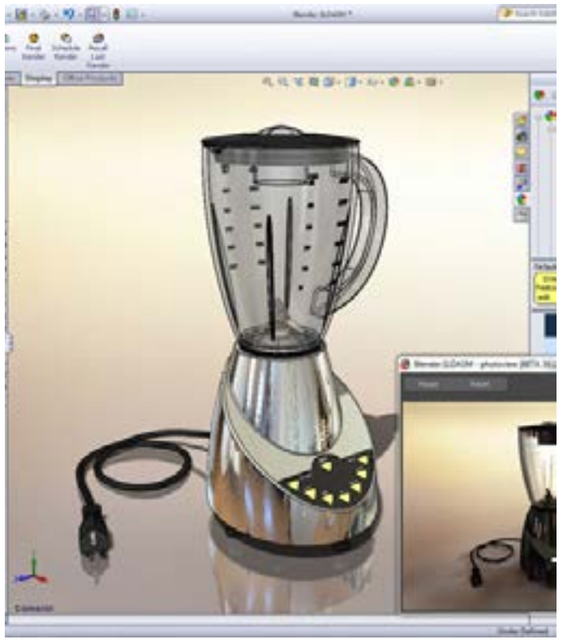
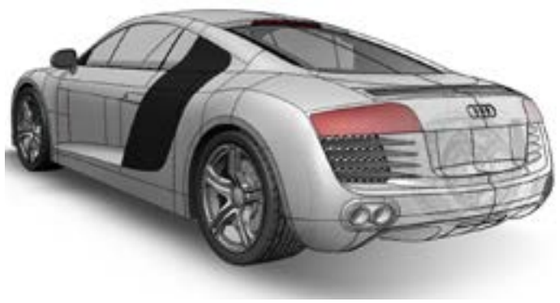
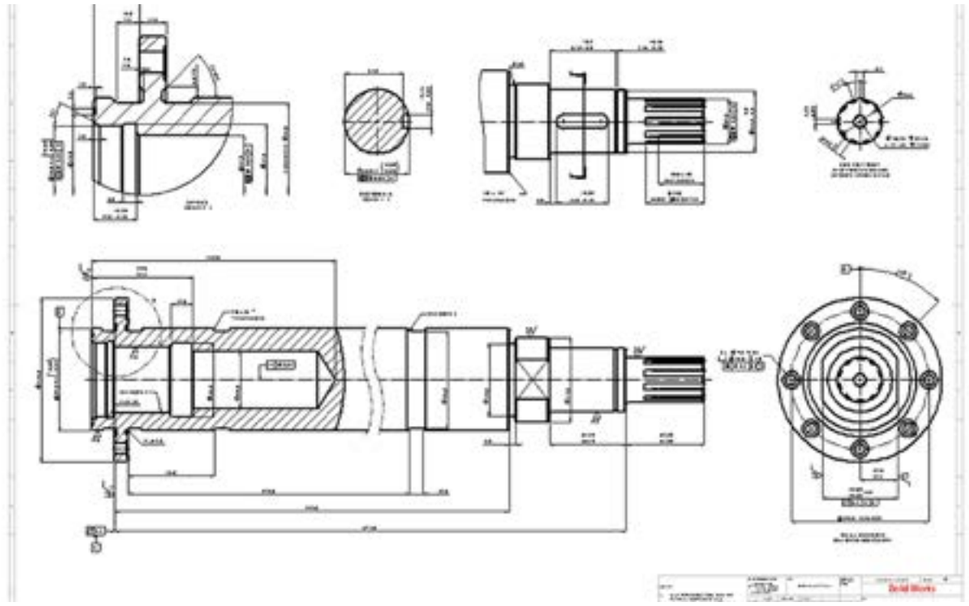


Finished sketch of a blender.
Source: http://www.thesolidexperts.com/products/solidworks-3d-mechanical-design/solidworks-professional

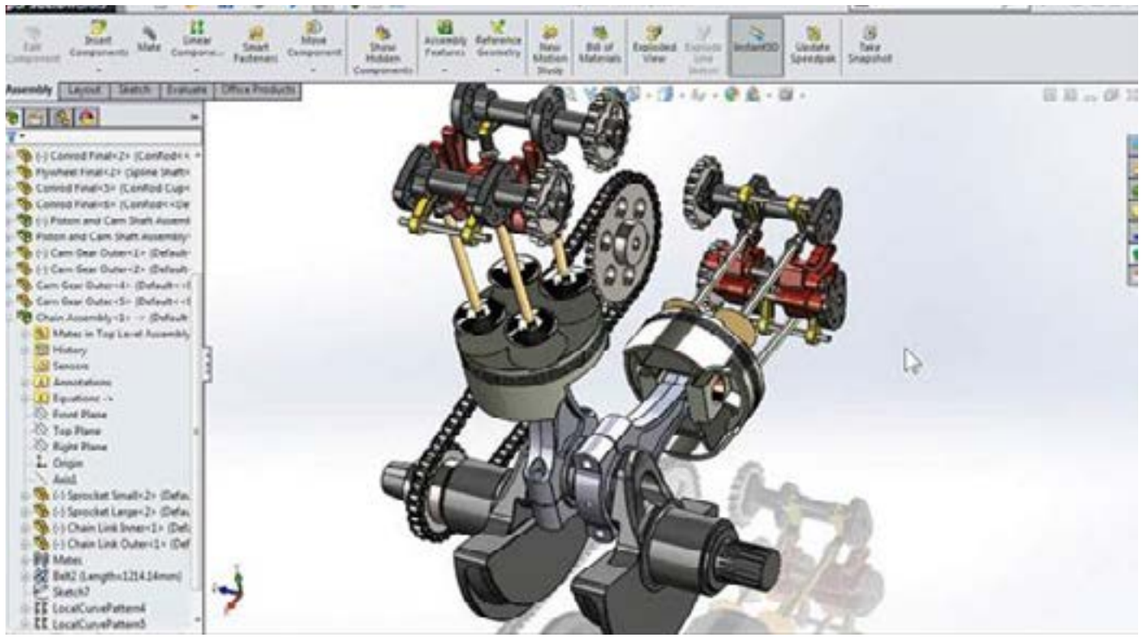


Finished sketch of an Audi R 8 in Solidworks.
Source: http://www.solidsmack.com/resources/how-to-model-a-audi-r8-car-in-solidworks-youll-love-this-video/

1 Abhishek C. Lad, A.S.Rao; International Journal of Emerging Engineering Research and Technology ; Volume 2, Issue 7, October 2014, p 157 ff



Technical drawing a turbine engine in Solidworks
Source: http://solidworks.fr/sw/image_categories.htm?thecategory=Drawings&GroupName=Product&Image_Page=4&maxrow=10



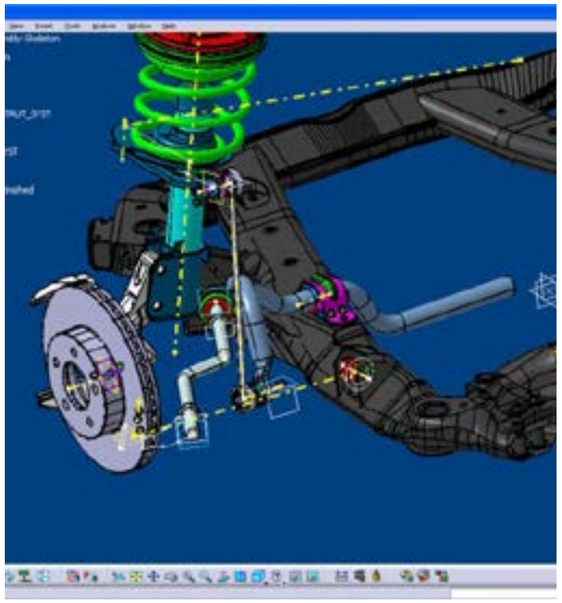
3D modeling of a motercycle engine
Source: https://www.lynda.com/SOLIDWORKS-tutorials/Modeling-Motorcycle-Engine-SOLIDWORKS/167705-2.html

Computer-aided Design

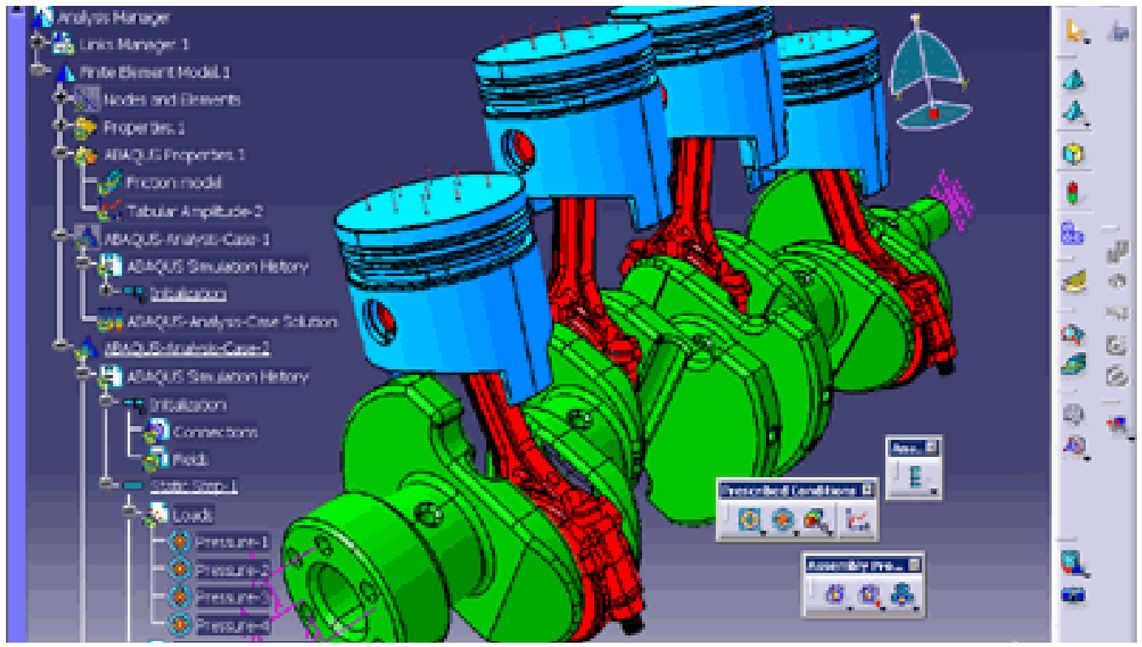
4.4. CAE

4.4.3. CATIA

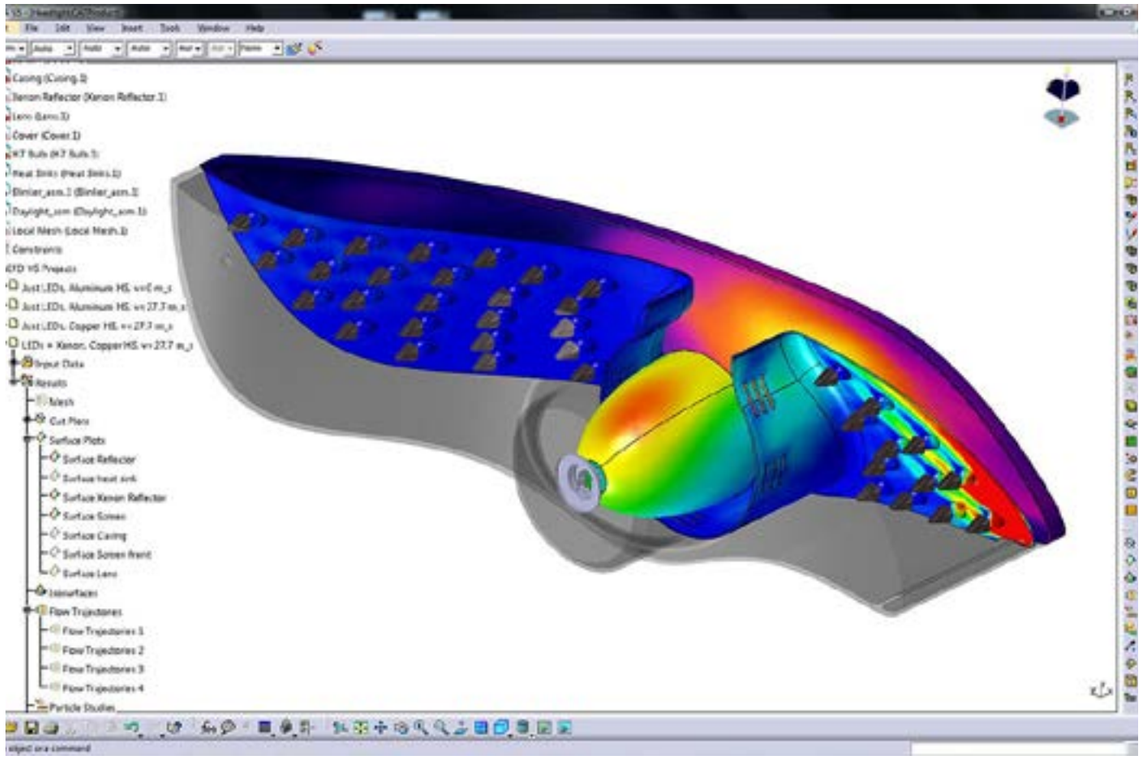
CATIA (computer-aided three-dimensional interactive application) is a multi-platform CAD, CAM (computer-aided manufacturing) and CAE software suite developed by the french company Dassault Systèmes.
It supports multiple stages of product development. Including conceptualisation, design, engineering and manufacturing. CATIA has a platform called 3DEXPERIENCE which inlcudes surfacing and shaping design, electronic systems design, mechanical and syste engineering.



3D modeling detail of a spring with a wheel disk
Source: http://www.uniplm.de/CATIA-PLM-Express-Mechanical-Product-Creation-42.html



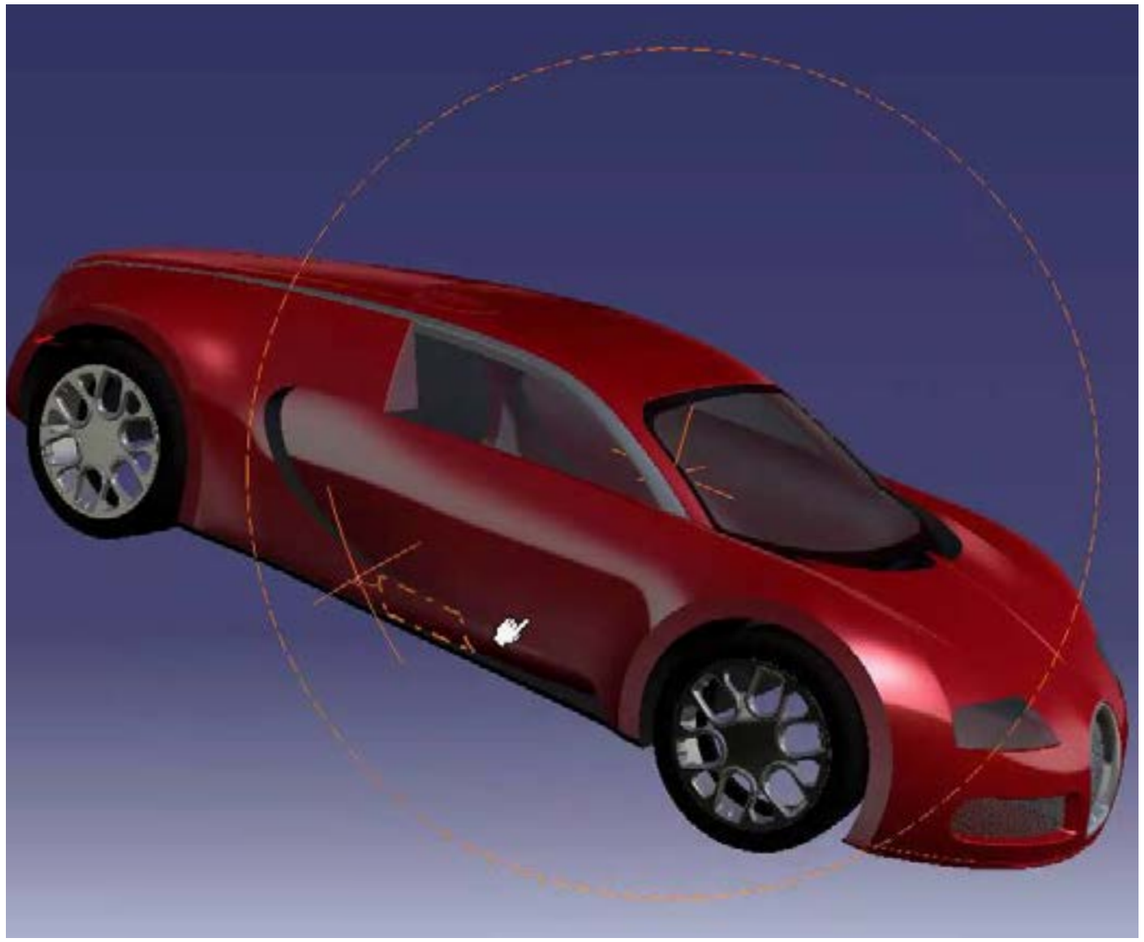
3D modeling of an engine in the cylinder detail.
Source: https://www.deanza.edu/cdi/catia.html



3D modeling of a termic circuit and fluid flow
Source: https://www.mentor.com/products/mechanical/floefd/floefd-catia-v5/

Computer-aided Design

The creation of 3D parts from 3D sketches, sheetmetal, molded, forged or tooling parts and composites is provided in CATIA. It's advanced in mechanical surfacing and BIW (used in automobile manufacturing where a car body's sheet metal components have been welded together).
It provides tools to complete product definition, including functional tolerances as well as kinematics definition. The program also offers a solution to shape design, surfacing workflow, styling and validate complex innovative shapes



3D modeling video of a Bugatti R18
Source: https://www.youtube.com/watch?v=jC9JP6gDPeE

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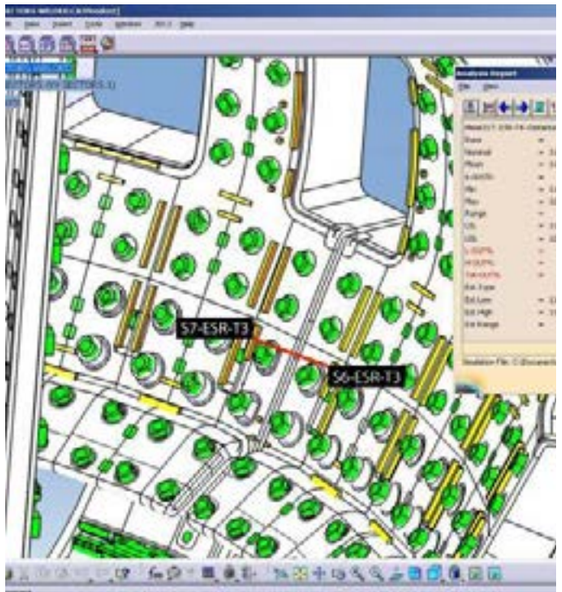
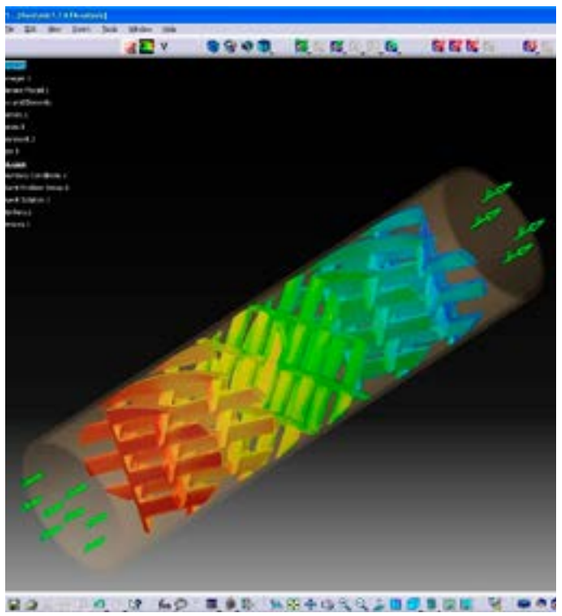
CATIA covers several stages of product design. Beginning by a sketch or 2D drawing up to the final 3D rendering. The files run in STEP (Standard for the Exchange of Product model data) format for reverse engineering and surface reuse.[1] CATIA delivers an unique extensible and open system engineering development which integrates the cross-discipline modeling, verification and simulation.
It uses the open Modelica language (object-oriented, declarative, multi-domain modeling language for component-oriented modeling of complex systems) to quickly and easily model the behavior of complex systems that can span multiple engineering disciplines. [2]



3D modeling detail of the inside of a capsule
Source: http://www.3dcs.com/catia.html



3D modeling of a termic circuit in a tube
Source: http://www.directindustry.fr/prod/ansys/product-9123-371838.html

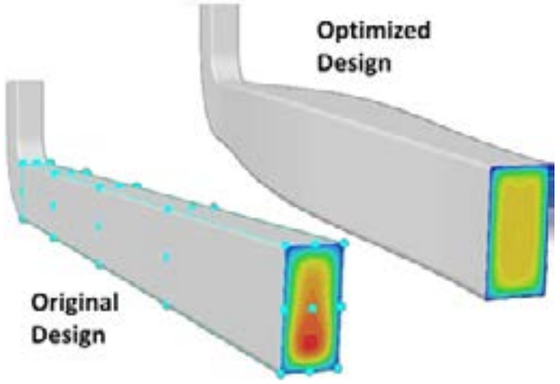
1 http://www.mecanicasolutions.com/software/catia/
2 http://www.claytex.com/products/catia-systems/

Computer-aided Design

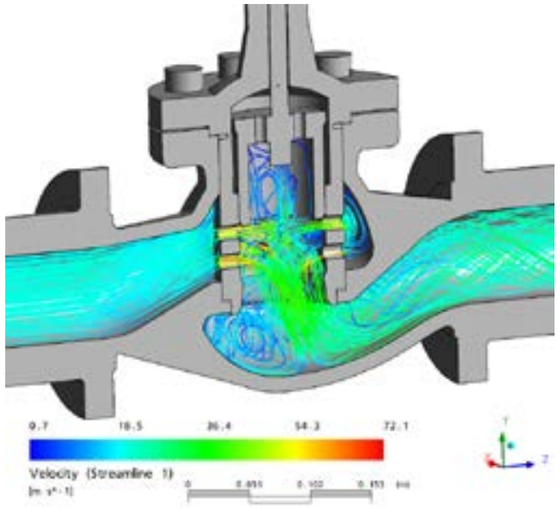
4.4. CAE

4.4.4. ANSYS

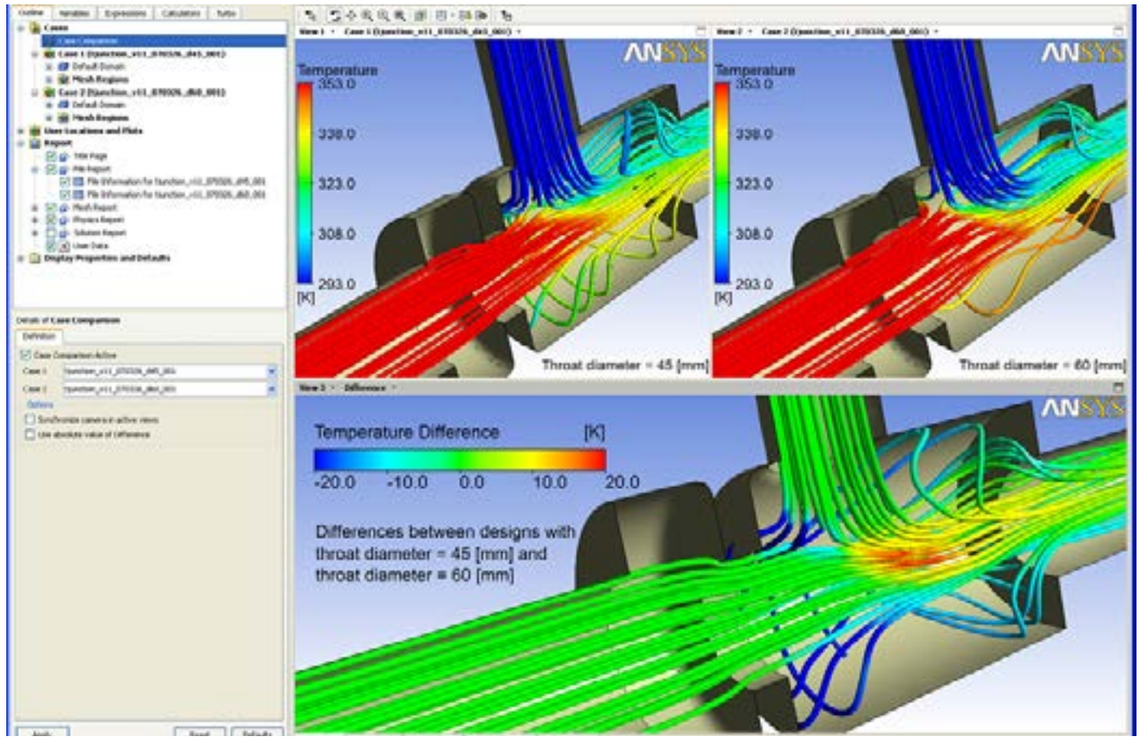
ANSYS is a CAE program developed by John A.Swanson in 1970 in the USA. It covers several engineering disciplines like FEA (finite element method), structural analysis, CFD (computational fluid dynamics), heat transfer and explicit/implicit methods.
It is devided in different software products for different needs. In the context of design the most important are ANSYS Autodyn which is a simulation tool that questions the respone of material from impacts like high pressure or explosions.
ANSYS Mechanical is a FEA tool for structural analysis, including linear, nonlinear and dynamic studies and Computional Fluid Dynamics can be analysed with ANSYS Fluent.



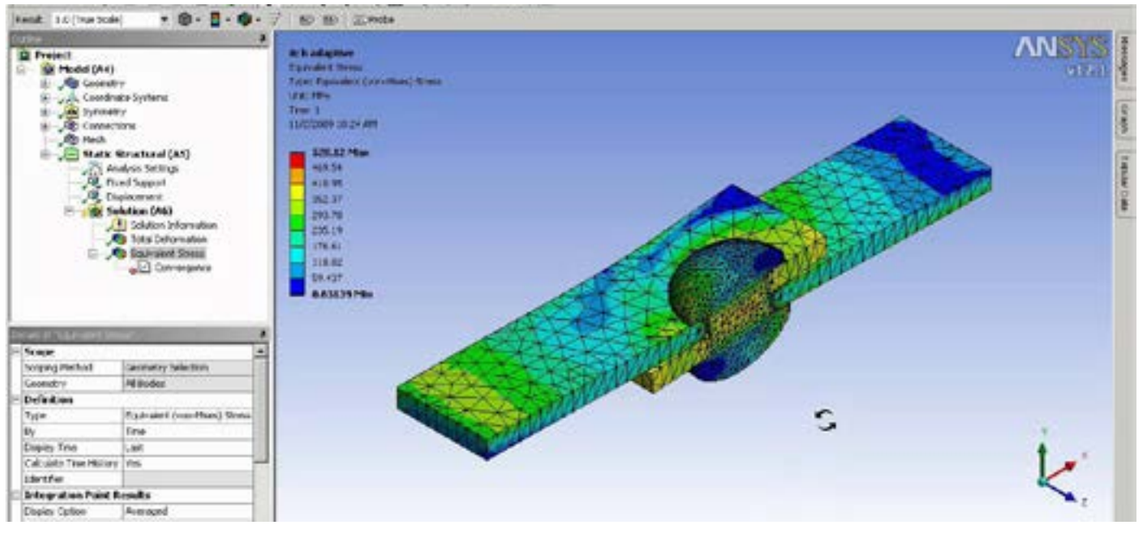
Optimisation suggestion for fluid dynamics
Source: http://wildeanalysis.co.uk/fea/software/ansys/fluid-dynamics/fluent



CFD - computational fluid dynamics
Source: http://resource.ansys.com/Products/Simulation+Technology/Fluid+Dynamics/Fluid+Dynamics+Products/ANSYS+CFD-0



Fluid analysis and optimisation
Source: http://wildeanalysis.co.uk/fea/software/ansys/fluid-dynamics/fluent



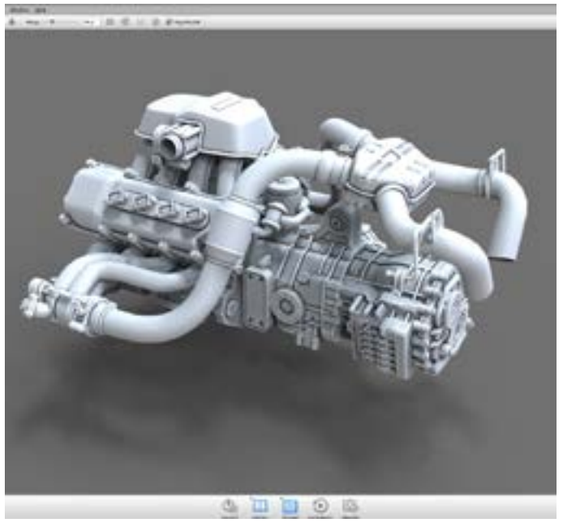
Video online of ANSYS Workbench running through a stress analysis
Source: https://www.youtube.com/watch?v=kfFpI2uK6rQ

Computer-aided Design

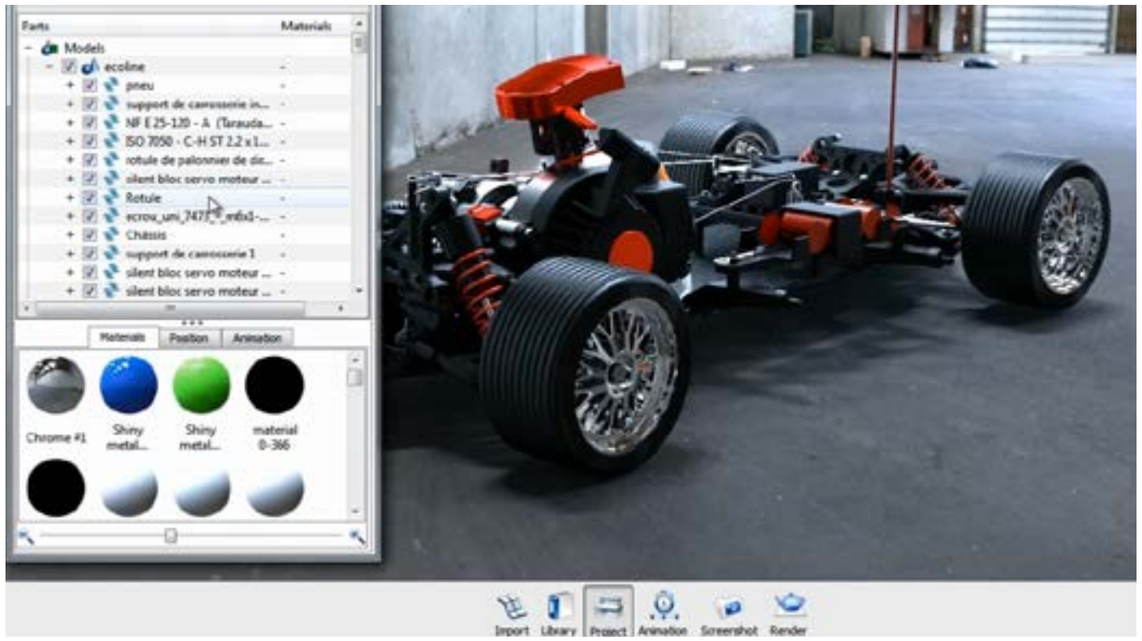
4.5. 3D animated programs

4.5.1. The addon to 3D modeling

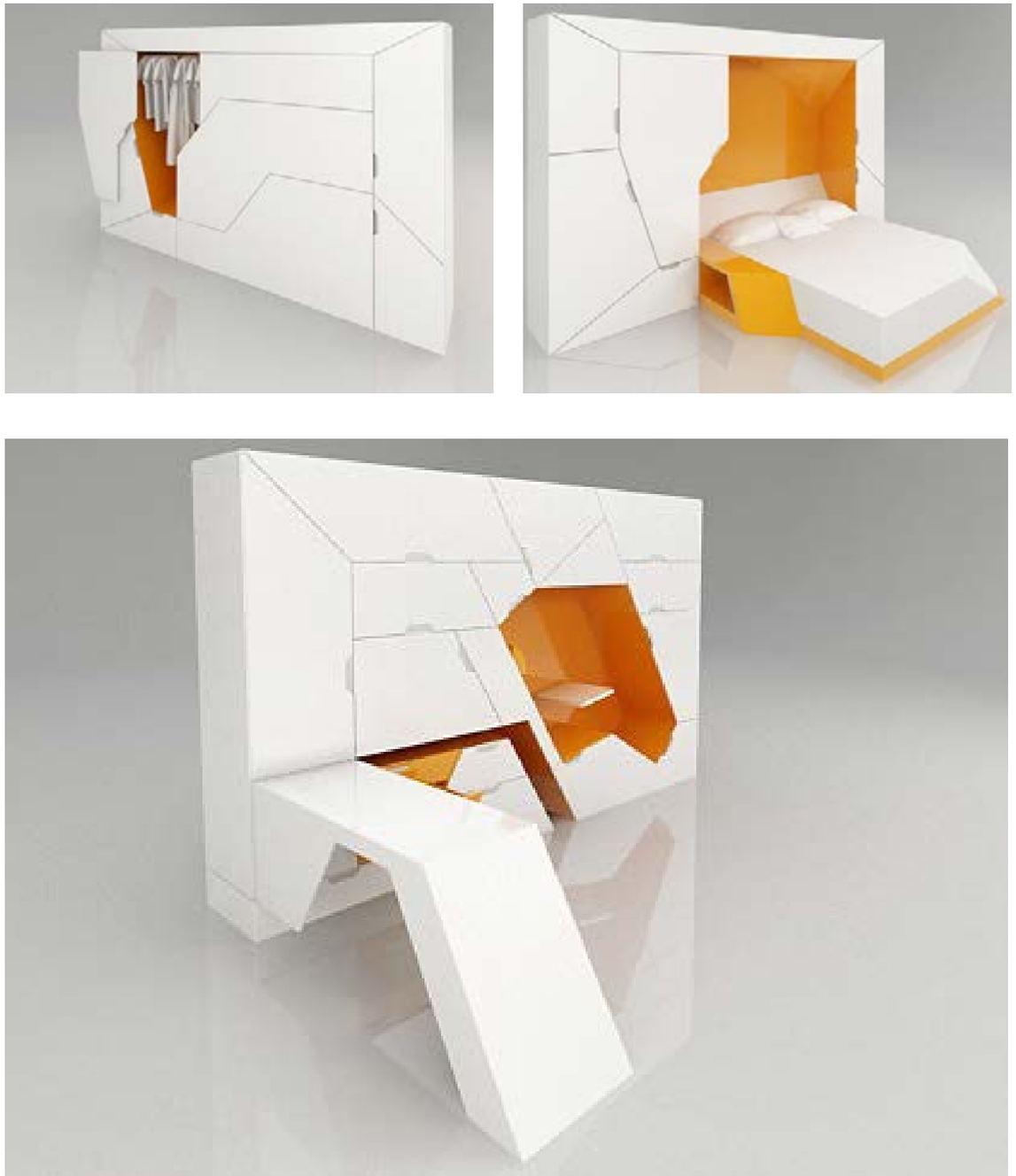
Computer programs used for developing a mathematical representation of any three-dimensional surface of objects, also called 3D modeling. The addons for increasing the outcome of the work are called 3D animated programs.
Those programs are used to bring models made in 3D modeling programs to perfection.
3D animation programs are able to show the designer how the product will approximatly look when it is finished with all its used materials and features.They also provide the ability to set the designed object in a context of space.
This function allows the designer to think further, to see the product in context and to imagine the result.



An engine rendered in Keyshot.
Source: http://www.cgfeedback.com/cgfeedback/showthread.php?t=6078



A cart car rendered in keyshot.
Source: https://www.keyshot.com/2011/keyshot-3-animation-materials-ui-tutorials/



Rendering of the space saving and modular concept Boxetti by Rolands Landsbergs
Source: http://cabinetspace.blogspot.fr/2012/09/space-saving-furniture.html

Computer-aided Design

Most common 3D animation programs are Cinema4d and Keyshot.
In contrast to AutoCad, Solidworks or Rhinoceros, who also have a 3D animation options, their rendering capability is much more satisfying and precise. In Rhinoceros for example it is possible to render an object with certain materials and effects, though it is not possible to set it in an enviroment. Furthermore the quality of the rendering isn't the best. Most of the time the effects look cheap or simply said too fake.
In Cinema4d or Keyshot on the other hand it is possible to upload a picture of a certain enviroment.
For example if a designer creates an interior object like a sofa, it is possible in Cinema4d or Keyshot to set that sofa in a therefore wanted space. Consequently 3D animated programs are indispensable for every product designer or architect.

Example for Keyshot. "The hidden bookcase"

Rendering of modular outdoor furniture by Fischer Möbel
Source: http://purecontemporary.blogs.com/behind_the_curtains/2010/06/modern-modular-outdoor-furniture.html

Seating module benches rendered in Cinema4d
Source: http://jefferywright.com/category/cgi-model-creation-design-and-rendering/contemporary-furniture-fixtures-lighting-3d-models/

Rendering in Cinema4d: Escofet Twig Modular Bench by pixelab
Source: http://www.turbosquid.com/3d-models/twig-modular-bench-escofet-3d-model/775673

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Computer-aided Design

4.5. 3D animated programs

4.5.2. Cinema4d

Computer programs used for developing a mathDeveloped in Germany by Maxon Computer GmbH, Cinema4d is one of the market leader in 3D modeling, animation and rendering applications. Besides animation, lightning, rendering, texturing and other common 3D features, the program is also capable of procedural and polygonal/subd modeling. Subd is a special algorithme to create smooth surfaces developed by Edwin Catmull and Jim Clark.[1]
Currently 4 variants are availabe from Maxon: Prime, Broadcast, Visualize and Studio.
In 2014 the 5th variant “Lite” which comes packaged with Adobe Effects Creative Cloud was released. The partnership between Adobe and Maxon opens new possibilities.
Maxon produced a plug-in called Cineware which allows any variant to create a smooth workflow with After Effects CC.

Escofet Hebi Modular Bench by pixelab rendered in Cinema4d
Source: http://www.turbosquid.com/3d-models/max-hebi-modular-bench-escofet/775751

The new addon “Arnold” support the physic-enginge feature and connects it with 3D animation of the human body
Source: https://www.solidangle.com/news/press-release-c4dtoa/

Cinema 4D has an interface and workflow that allows to concentrate on the creative process without having to worry about technical details.
It is inevitable in 3D printing and essential in almost every design field. The user surface isn’t easy to understand from the beginning but there are loads of tutorial availabe online and after investing some time to get used to the program it can ease the way of creation enormously for the designer. In the latest release the texturing got upgraded and now it’s even possible to render a single organic fiber. Also there is a new physic-engine which allows to understand the movement of a product (for example a ball).

Camaleonda Modular Sofa by Martin Szeme rendered in Cinema4d
Source: http://www.turbosquid.com/3d-models/max-classic-modular-camaleonda-sofa/1017318

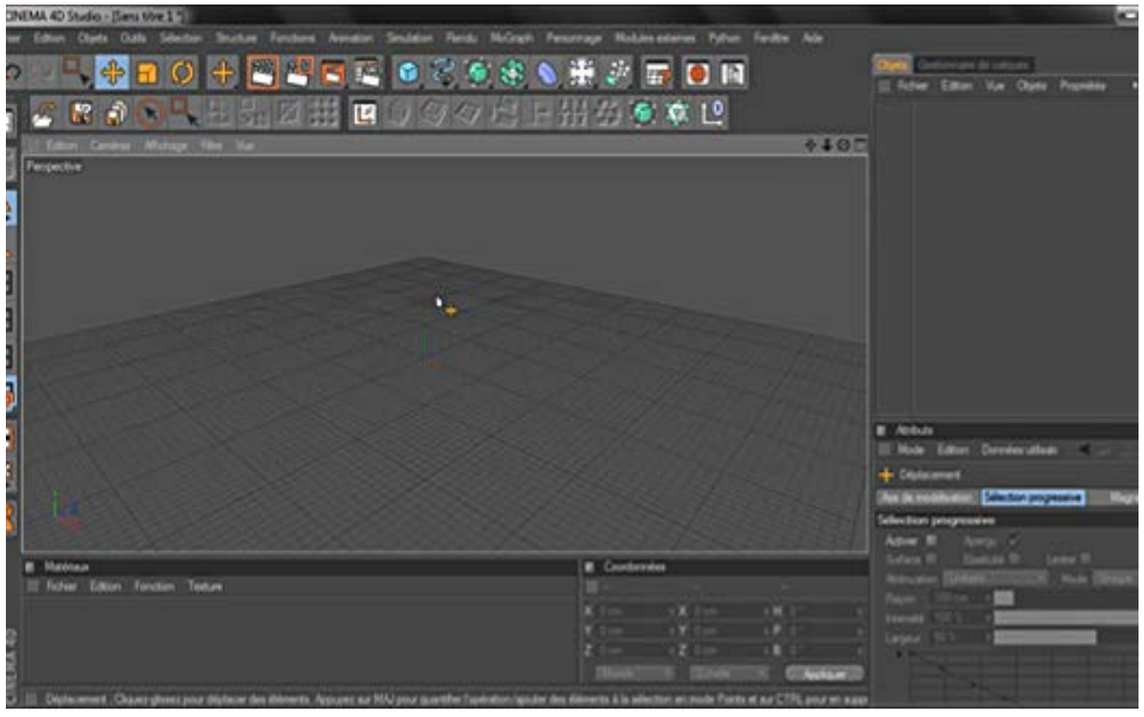
1 Stam, J. (1998). “Exact evaluation of Catmull-Clark subdivision surfaces at arbitrary parameter values”. Proceedings of the 25th annual conference on Computer graphics and interactive techniques - SIGGRAPH ‘98 ; p. 395–404

Computer-aided Design

Following pictures show some example of the interface and the possibilities with Cinema4d.

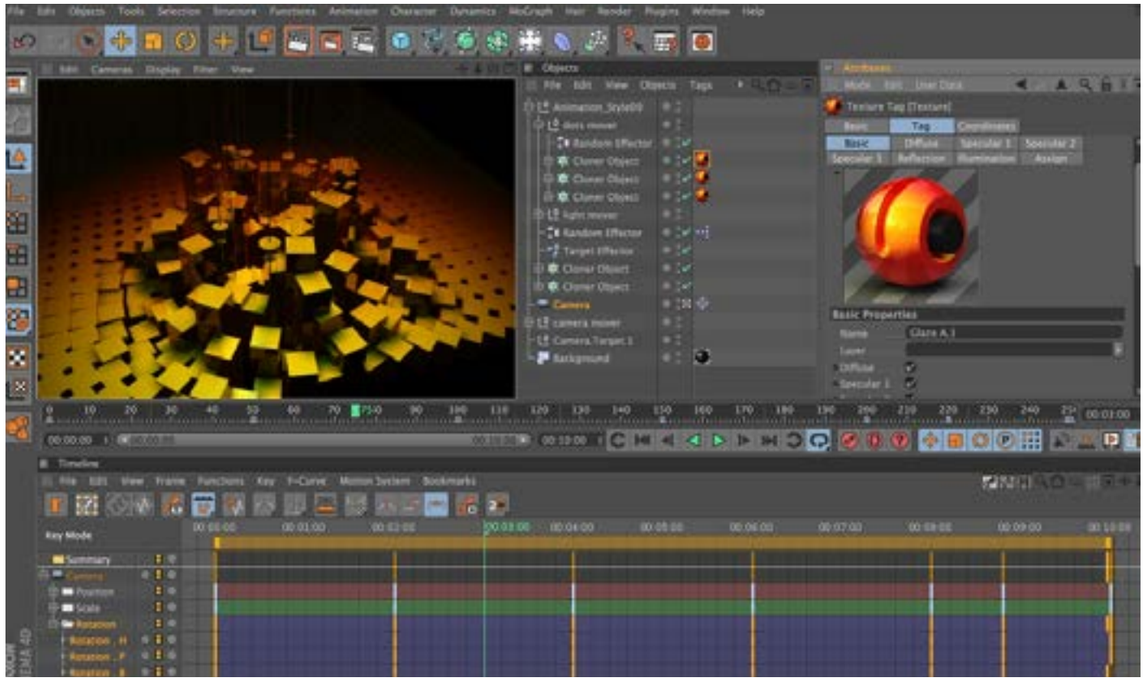
Example for Cinema4d. Interior design, table with chairs.
Source: http://www.indigorenderer.com/indigo-cinema-4d

Rendering of a BMW in Cinema4d
Source: http://cinema-4d.en.softonic.com/mac



Example for an empty interface in Cinema4d
Source:http://www.wizix.fr/blog/2-ressources/blogtuto01-personnaliser-son-interface/

Example for Adobe After Effects
Source:http://www.creativebloq.com/after-effects/tutorials-1232661?page=1



Example for Cinema4d broadcast
Source:httphttp://www.maxon.net/de/news/press-releases/singleview/article/maxon-continues-role-as-3d-motion-graphics-leader-with-introduction-of-cinemanbsp4d-broadcast-edit.html

Computer-aided Design

4.5. 3D animated programs

4.5.3. Keyshot

Keyshot is a Luxion - advanced lightening technologies- product and is as well a 3D modeling and animation program like Cinema4d but the user interface is a lot simpler and therefore easier to understand. Technically it's an interactive ray tracing and global illumination program. It feartures a real-time workflow and has accurate material and environment presets.
The rendering speed in KeyShot cannot be compared. No matter if on a small laptop or a networked server with multiple CPUs, KeyShot will use all the cores available.
It's easy to import data and after allocate certain material with a dragging and dropping system. All enviroment settings are minimal but adequate.
The rendered files are exported as .jpeg which makes it compatible to every common operating system.
Keyshot also launched several plug-ins. Thereunder Autodesk Maya, 3ds Max and Fusion 360.

Rendering of a foldable and therefore spacesaving scooter: The INU by Israeli company Green Ride
Source: http://mashable.com/2015/11/17/inu-smart-scooter/?utm_cid=mash-com-pin-link#ThDvneW9fcqR

Real time rendering and ray traceing of a watch
Source: http://www.simplyrhino.co.za/products/keyshotfeatures.html

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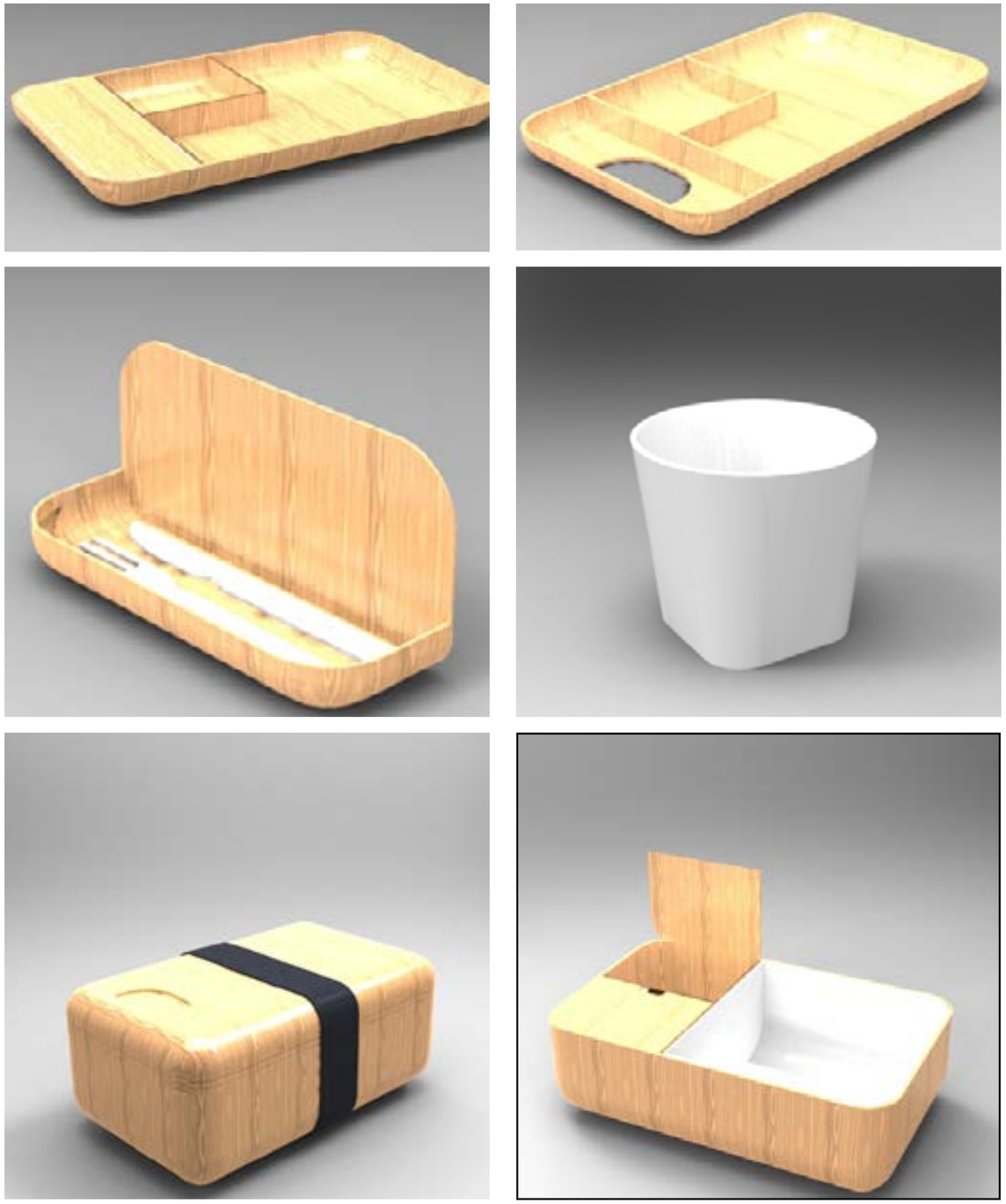
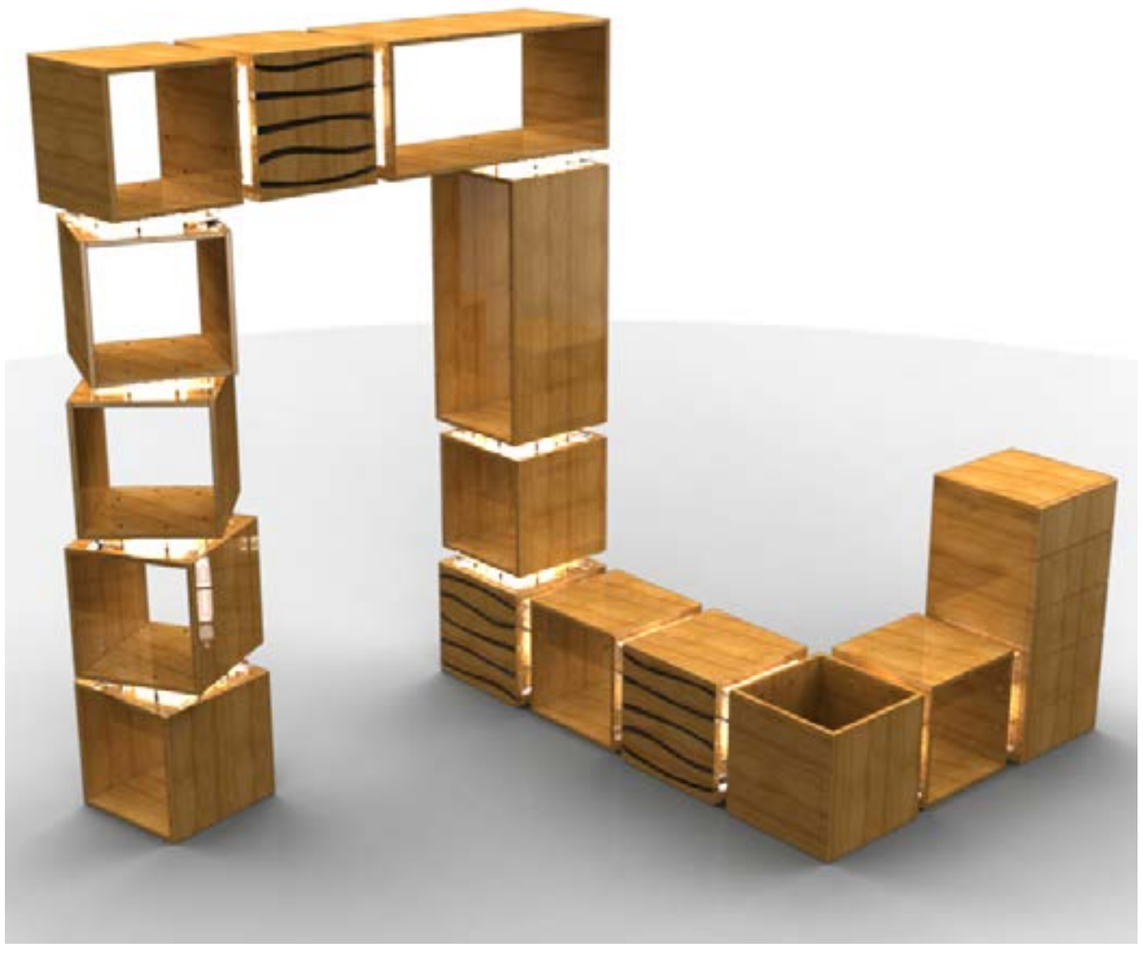


Rendering in Keyshot of "the BouffeBox".

Computer-aided Design



Rendering in Keyshot of the modular shell Phaos by Giacomo Pollesel
Source: http://www.coroflot.com/giacomopollesel/PHAOS-System-of-modular-furniture-for-home-interiors

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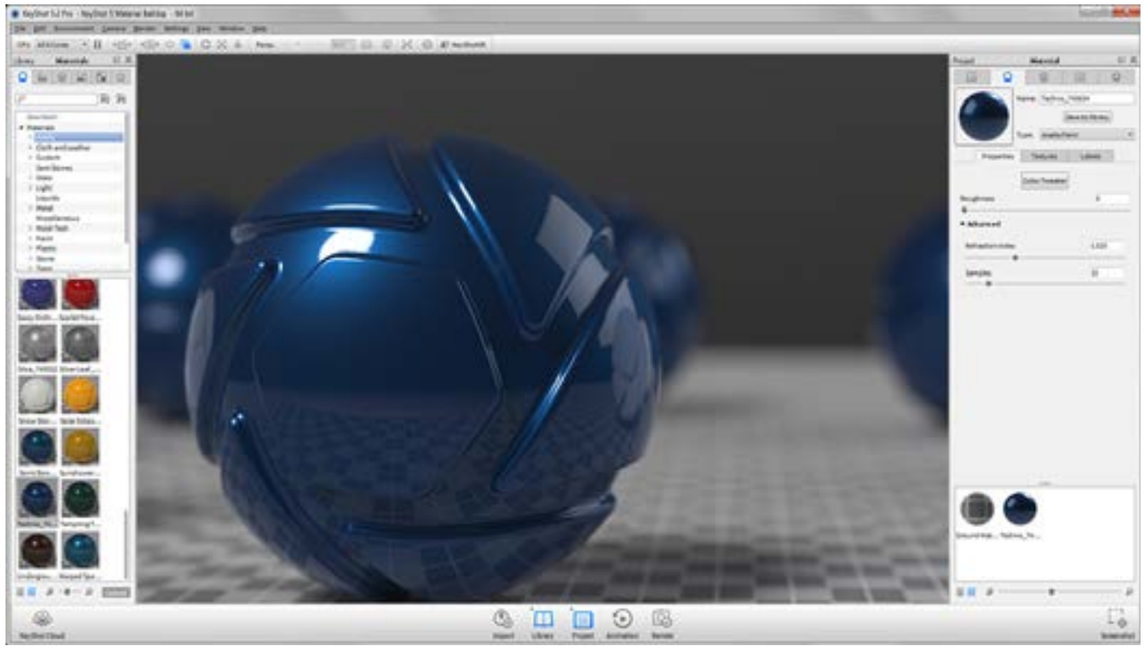


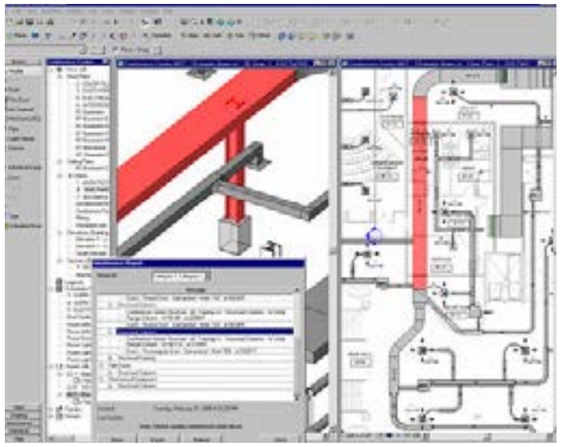
Example for the interface in Keyshot
Source: http://www.luxion.com/about.html

Modular storage kit by HYVE rendered in Keyshot
Source: https://www.keyshot.com/2014/herbst-produkt-rocks-kickstarter-hyve-modular-organziation/

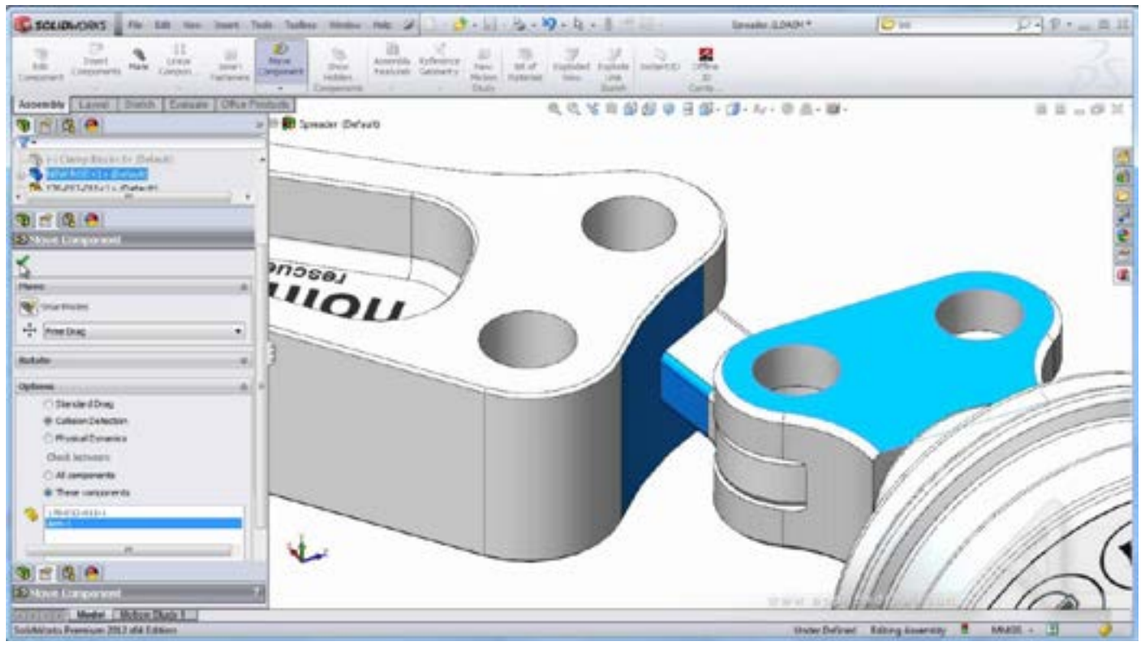
Modularity and Interference checking

5.1. Meaning of interference Checking

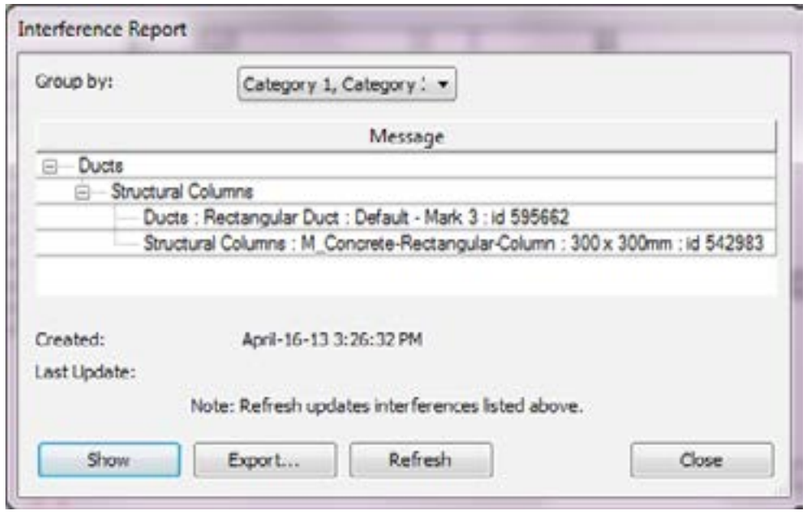
An interference check itself is a feature included in several CAD programs to verify that after assembeling different parts of the object every connected surface is closed. This is very important for the production as it saves time and development costs and consequently increases productivity. SOLIDWORKS, AUTODESK Revit and Siemens NX CAE are the most developped programs when it comes to interference checking.



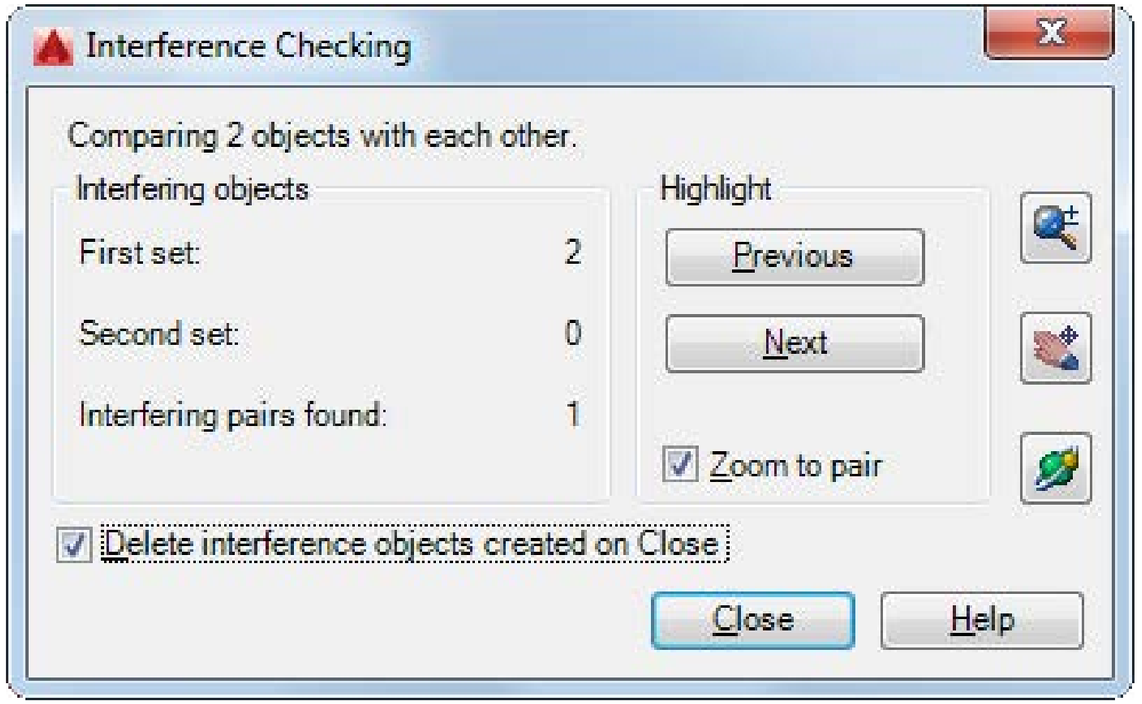
Example for interference checking in Autodesk Revit
Source: http://www.cadalyst.com/aec/1-2-3-revit-bim-mep-engineering-3245



Video explanation for the use of an interference check in Solidworks
Source: https://www.youtube.com/watch?v=crWpQ6O9DV4



The interference report in BIM jedi (former Revit)
Source: http://bim4scottc.blogspot.fr/2013/04/interference-checking-in-revit.html



Interference checking dialog box in Autodesk
Source: https://knowledge.autodesk.com/support/autocad/learn-explore/caas/CloudHelp/cloudhelp/2016/ENU/AutoCAD-Core/files/GUID-5809AAB2-5DE7-4560-8F51-41B0D2A3A4E1-htm.html

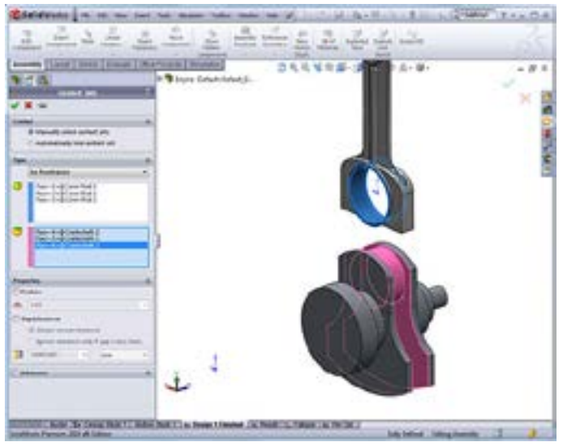
Modularity and Interference checking

Mismatched and misaligned holes or fasteners, component interferences and incorrect toleranc-ing of manufactured parts are the main causes of high rework and scrap costs on the assembly floor. When using only a 2D CAD tool, it is very difficult to uncover these issues before going into manufacturing.
In Solidworks for example the tools help to verify if the designs will fit, assemble and operate cor-rectly before manufacturing any parts.
Interference checking finds issues early in de-sign, that means as well giving more time to make less costly fixes. In Solidworks those fea-tures include:

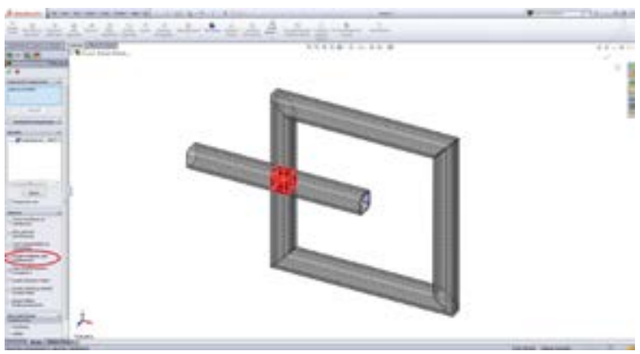
2D and 3D collision detection > meaning all parts fit and movable as intended before building any prototypes

Hole misalignment and thread mismatch checks > mating parts, mounting holes and fasteners align and threads match

Tolerance analysis > Optimises manufacturabil-ity beginning with dimensions and tolerances long before getting to production.

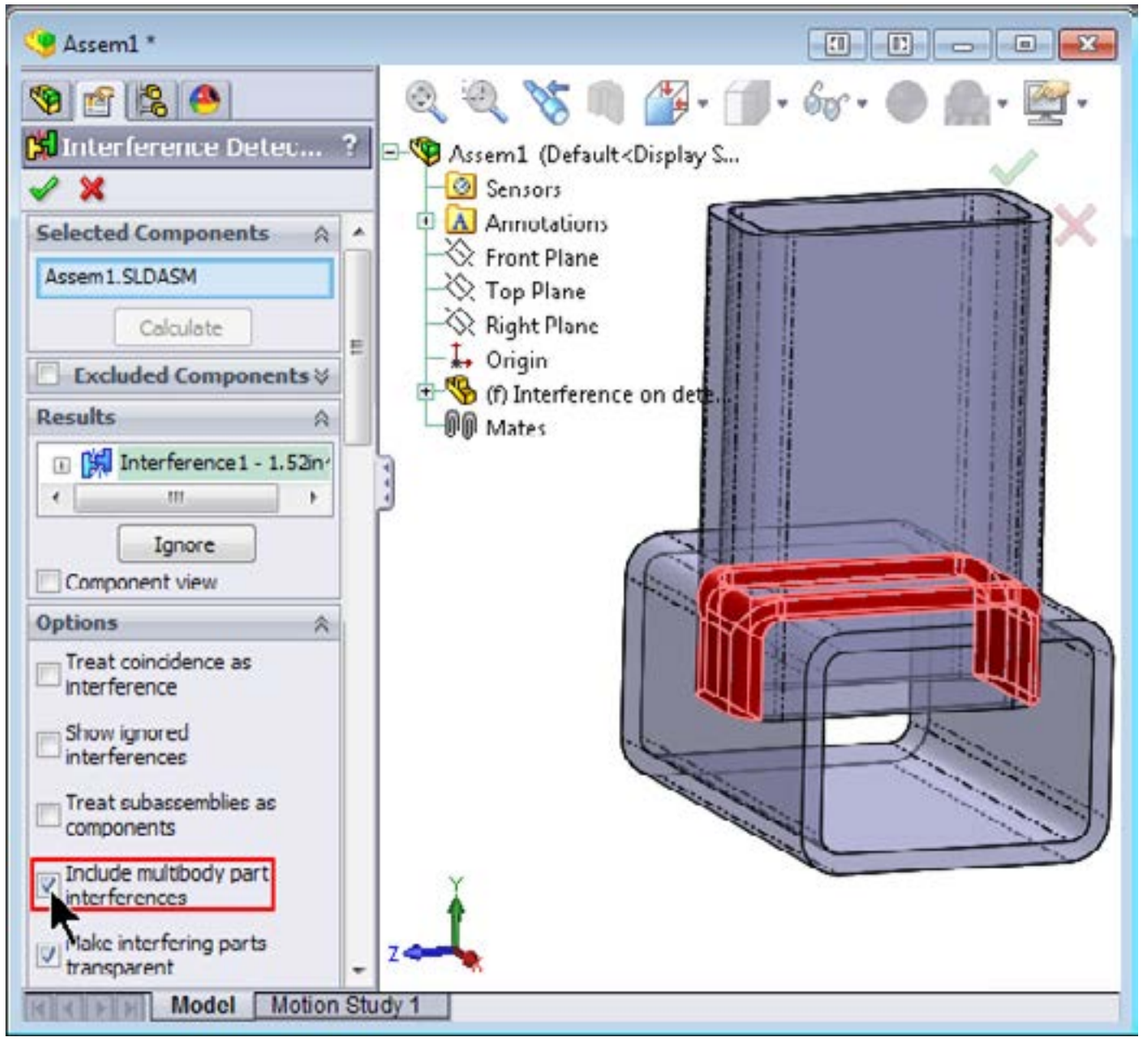


Stress analysis on a SolidWorks assembly
Source: http://www.cadalyst.com/manufacturing/under-standing-contact-solidworks-simulation-13526



Interference check of a weldment in Solidwork
Source: http://www.javelin-tech.com/blog/2013/08/interference-detection-for-a-weldment/

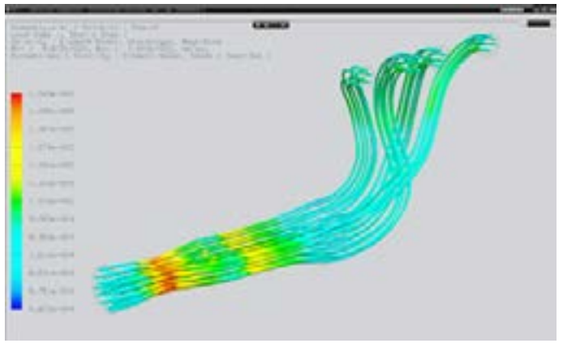
Technically those features are the same in ev-ery CAD program, some are more developped some less. In any case interference checking is important for the production, no matter if the ob-ject is a small piece or a big one.



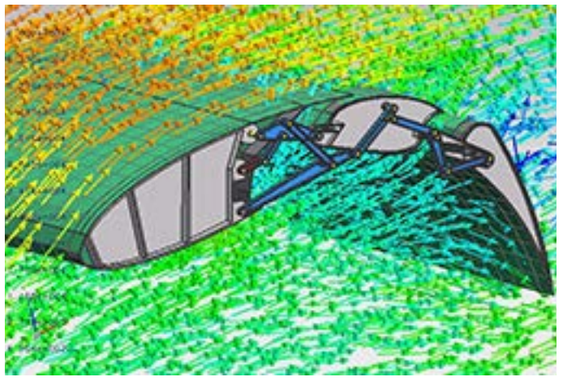
A check for Interference in between multiple weldment structural members in SolidWorks
Source: http://www.ddicad.com/blogs/techcenter/2013/05/17/interference-on-detection-on-weldments/

Modularity and Interference checking

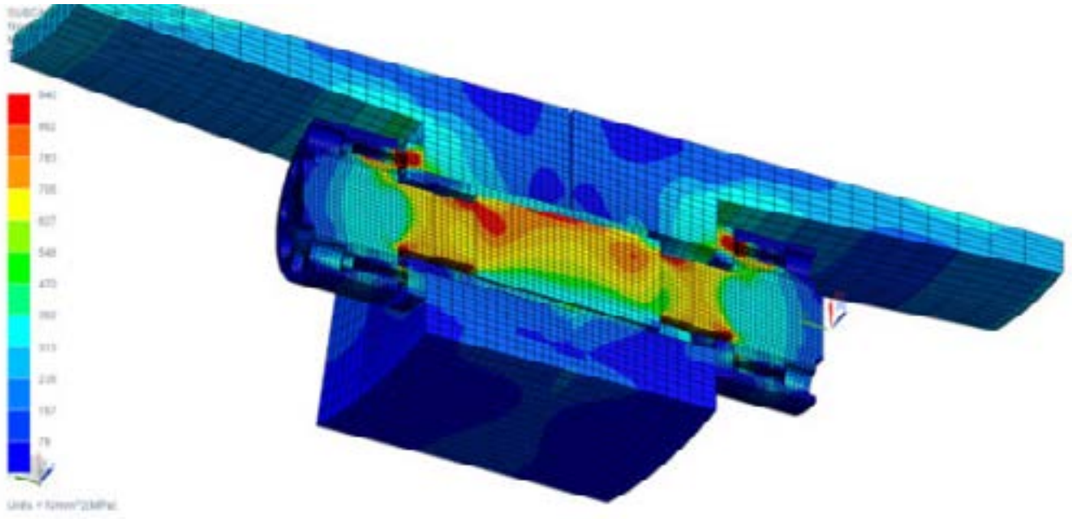
Siemens NX CAE in contrast sets value on engineering factors that go beyond kinematic solutions, meaning including objects like bushings or hoses that introduce an element of flexibility or compliance in the system.
NX CAE provides a multibody dynamic solver which can compute the displacement and postition of assembly components connected to springs, bushings and flexible bodies.
Additionally, NX CAE makes it quick and easy to solve motion analysis directly within the NX environment because it can automatically convert the CAD geometry assembly into a motion model. By using the geometry directly, it is possible then to get a true understanding of how a mechanism will behave in its operating environment and determine whether there need to be design changes to avoid interference issues.
However in the context of this chapter the meaning of interference checking must be understood more globally. **Interference check** itself is only a tool in CAD but further interpretated interference checking shall be an **allegory** and reflect the part of the designprocess where there is a need of computer softwares to optimise a product.
Consequently if a well functional modular product shall be designed and produced it is important to pre-check the interferences with a CAE program to avoid mistakes in the manufacturing or in the utilisation after.



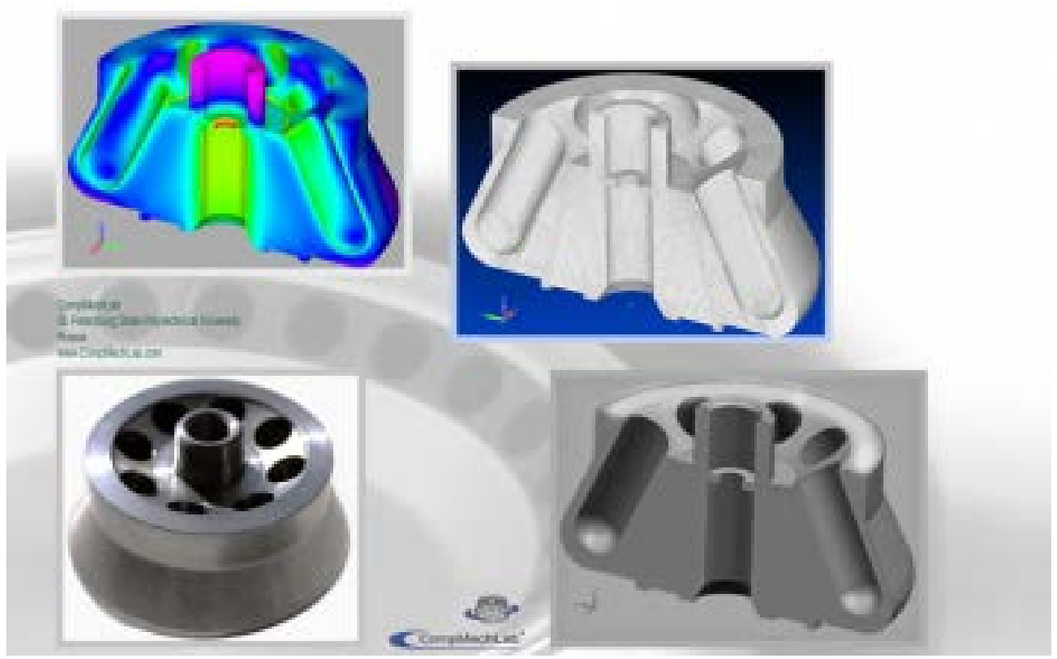
Siemens PLM (product lifecycle management) software
Source: https://www.interempresas.net/MetalWorking/Articles/43299-Siemens-PLM-Software-redefines-CAD-CAM-CAE-for-the-NX7-productivity.html



Simulation of fluids and airstreams in Siemens NX CAE
Source: https://www.plm.automation.siemens.com/de_at/products/simcenter/3d/flow/compressible-flow.shtml



NX CAE is used for advanced non-linear calculations to analyze stress states, deformations and movements in joints
Source: http://www.nord-lock.com/bolted/nord-lock-group-uses-siemens-nx-cae-develop-cutting-edge-technologies/

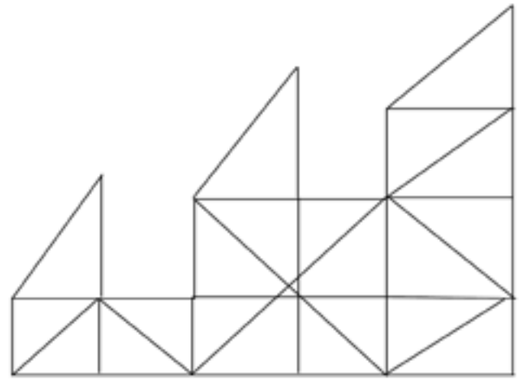


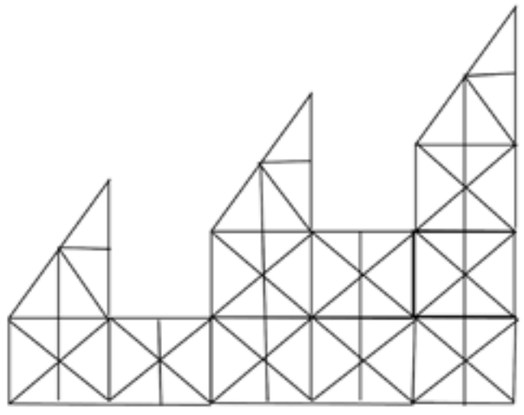
Technologies for product development (design, simulation and manufacturing productivity).
Source: https://www.cardsplmsolutions.nl/en/plm-software/nxa

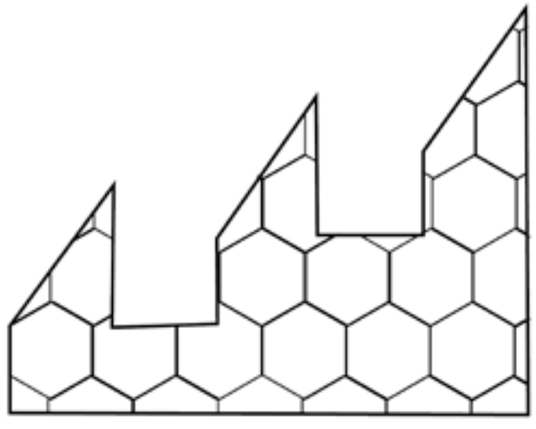
Modularity and Interference checking

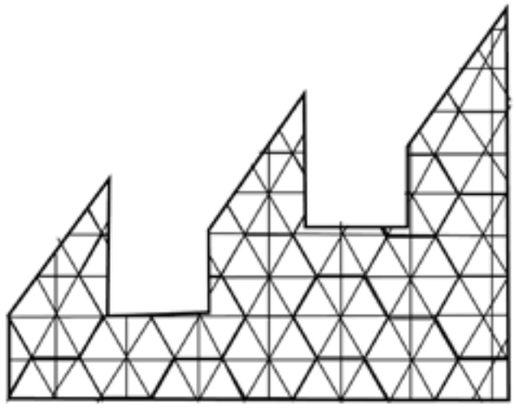
5.2. CAD and Interference checking on a working example

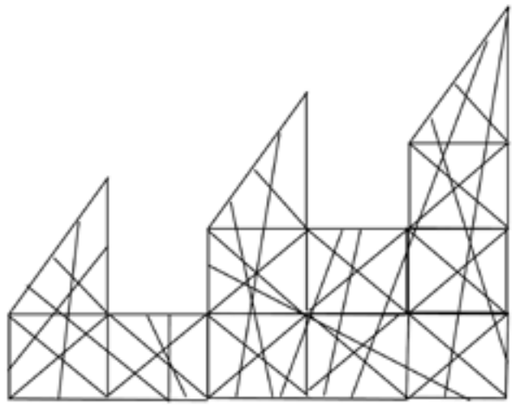
In the second year of studies I designed a modular tribune for the city Kelheim.
The task was to improve the quality of life in the small village and consequently to attract more tourists. The lead sentence during this project was "form follows function".
I chose this working example because the design was mainly affected by the engineering conception for which I mostly used CAD and CAE programs which were Rhinoceros, Keyshot and ANSYS.
The tribune should be easy to assemble and dismount, not taking much storage space and have the possibility to be arranged either aligned or in a circle with 10°.
The first program I used was Adobe Illustrator to find a stable and attractive framework.

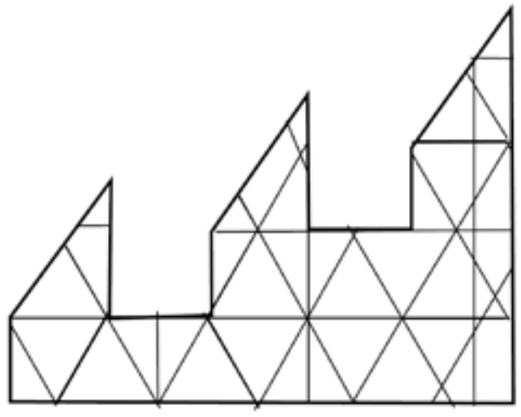


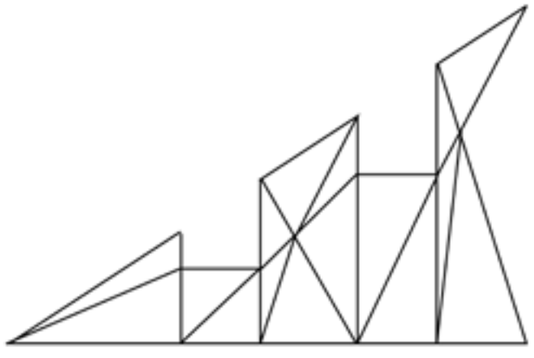


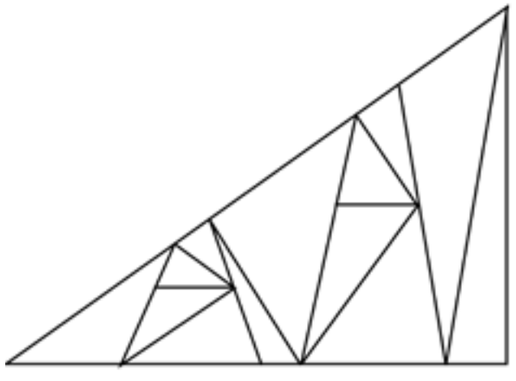






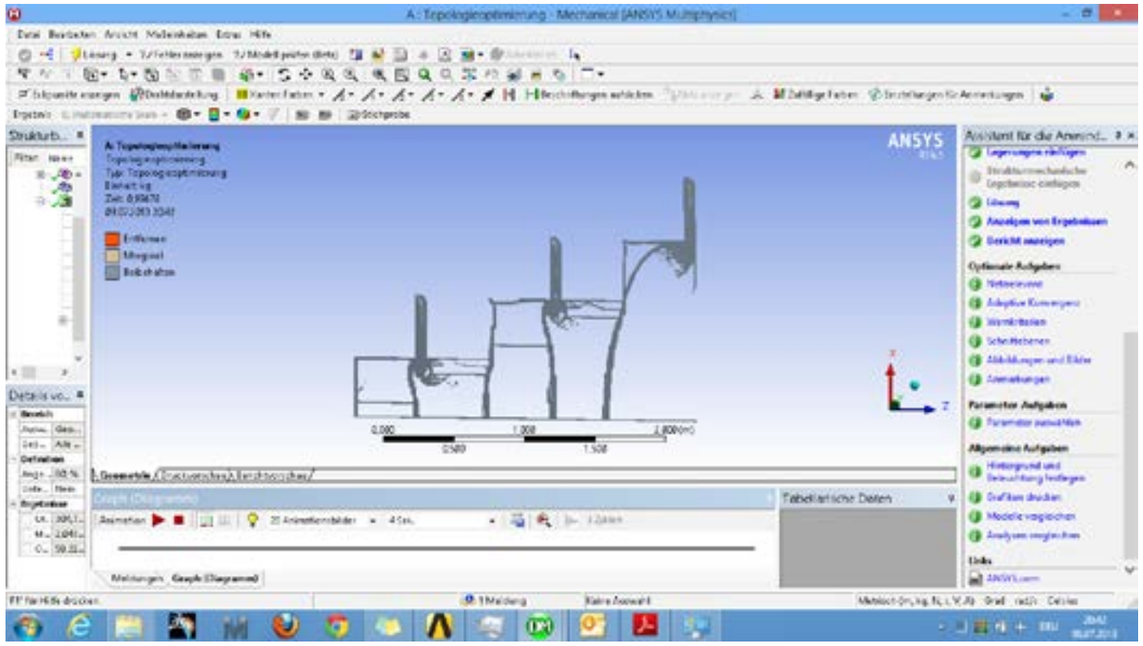




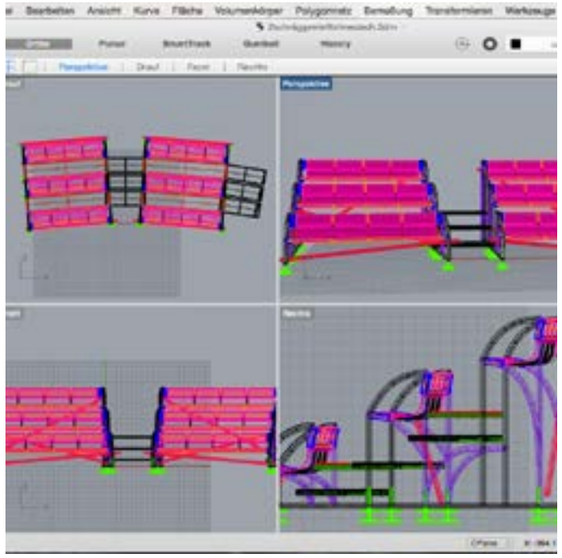


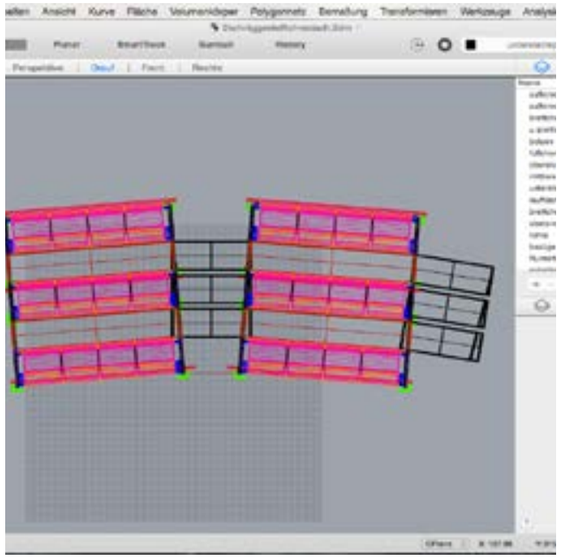
Modularity and Interference checking

To calculate the operated forces I uploaded the Illustrator sketches in the free student version of ANSYS which is an engineering analysis software across a range of disciplines including finite element analysis, structural analysis, computational fluid dynamics, explicit and implicit methods, and heat transfer.
An interference check was inevitable to garantee the stability of the framework.

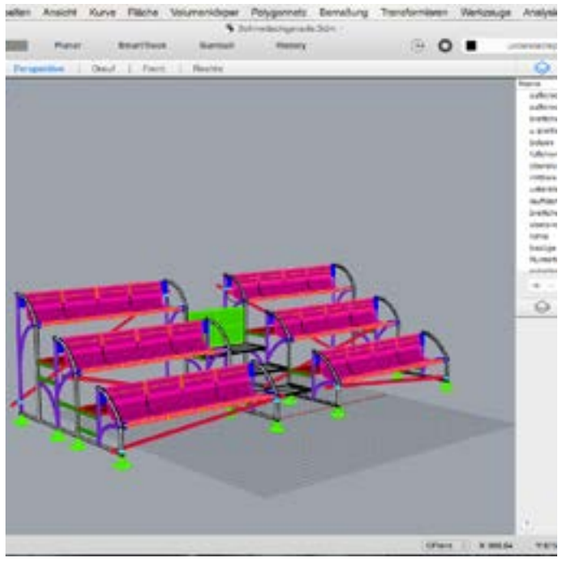


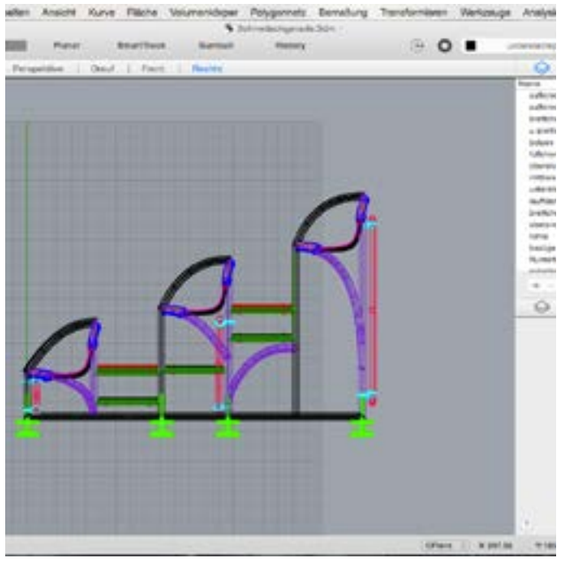
I knew the operating forces so I could get started with modeling in Rhinoceros.



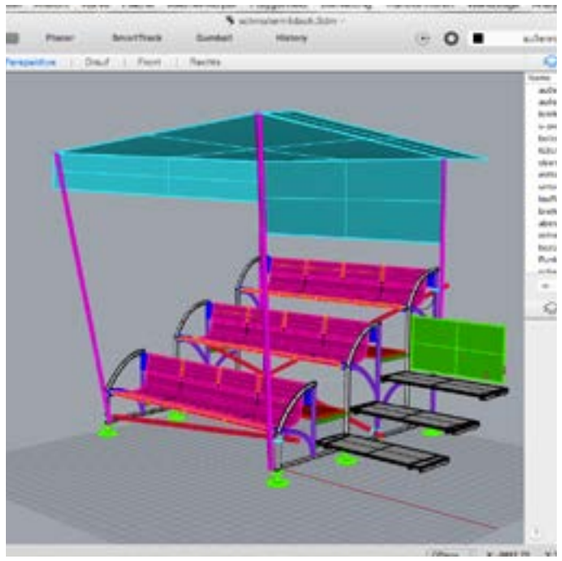


Arranged in a 10° angle

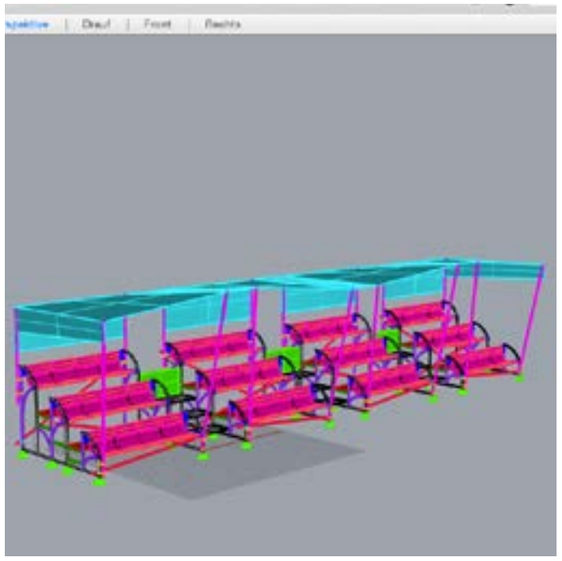


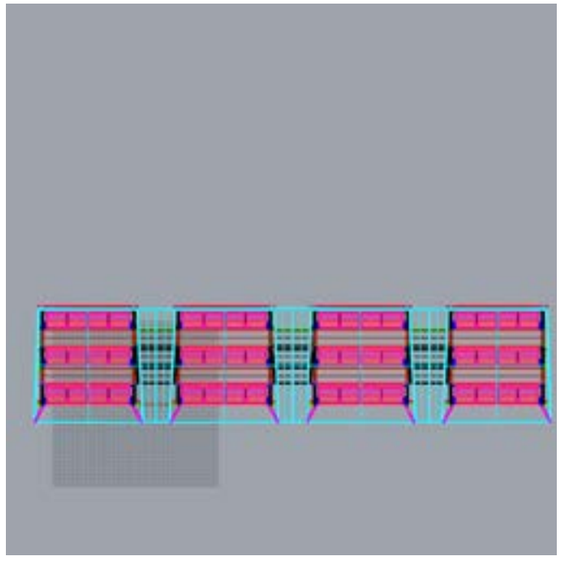


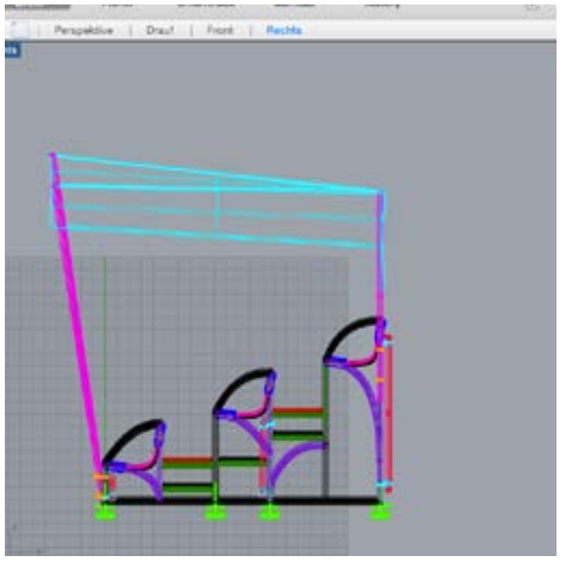
Modularity and Interference checking



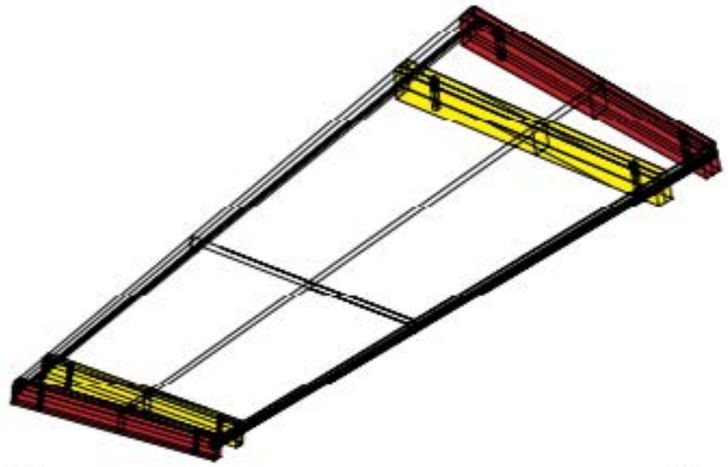
I also added a roof part to provide protection of weather circumstances.



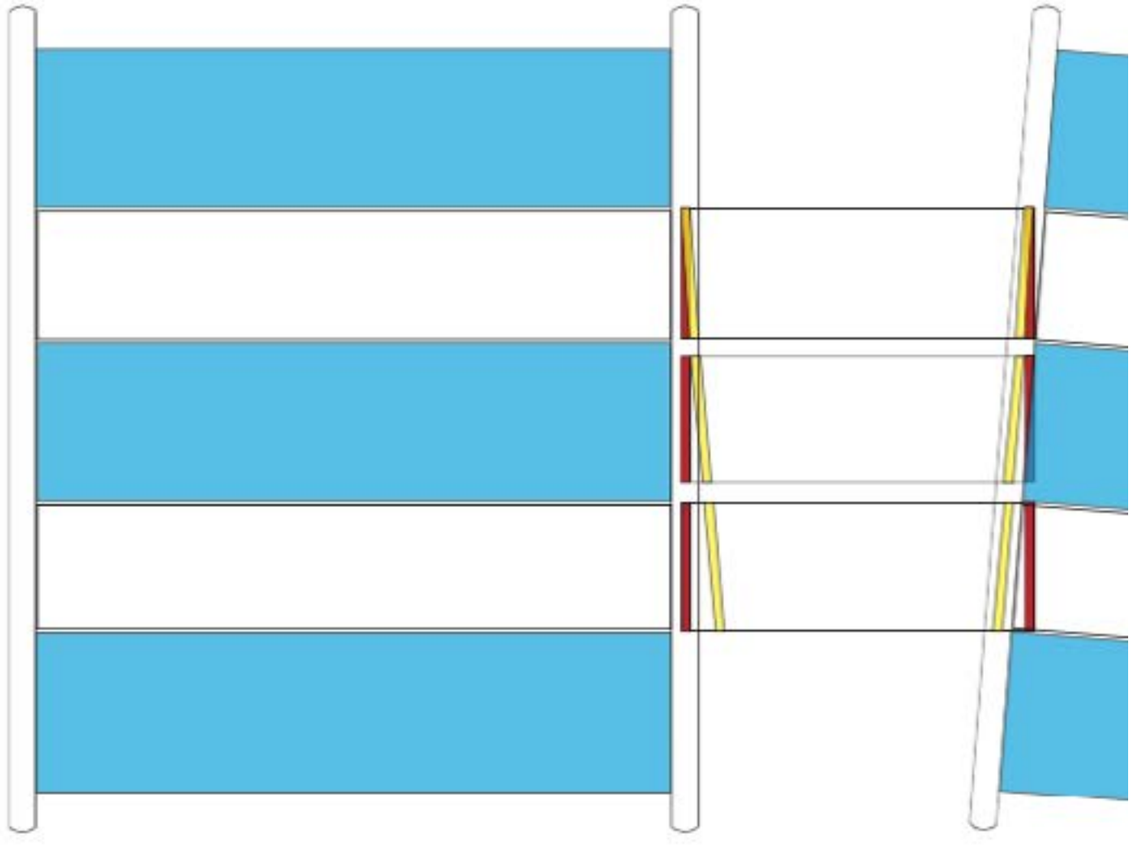




The tribune aligned. The modular elements are very well visiable (red). The stairs in the middle can be arranged straight or in an angle of 10° to raise the flexibility of the use.

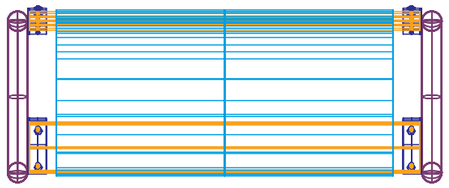


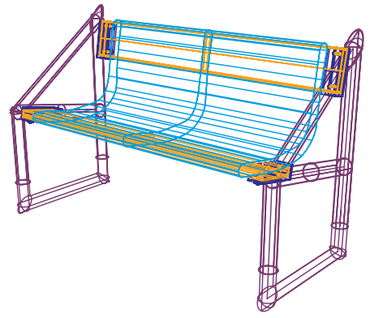
Um die Flexibilität bei de
lichen zu können, kann n
schiedlich mit den Treppe
der rot markierte Teil in d
hängt, wodurch die Tribü
die Tribünen schräg anzu
Teile in die U-Profile eing
in der gelben/schrägen
wird, weshalb die U-Prof
fen sein sollten.

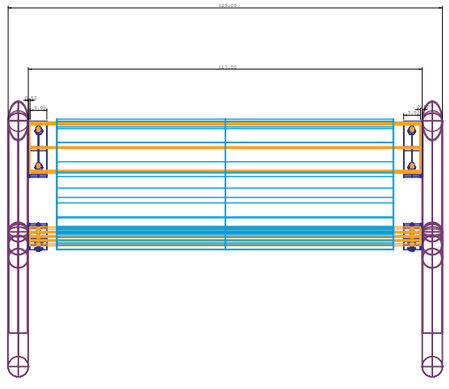


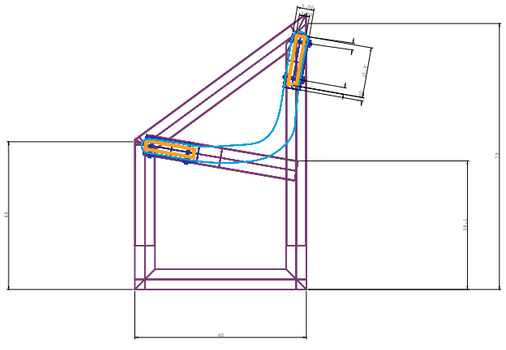
Modularity and Interference checking

It was only necessary to build 1 prototyp which was a 1:1 element of the tribune.
Due to a lack of personal resources in tools the form of the framework had to be straight and not rounded as in the original, nevertheless the bench was statically stable, confortable and therefore approved.
Using CAD and CAE while doing this project saved a lot of time during the design process and also pre-optimised the object already before the construction.
After talking to an engineer he furthermore assured me that the interference check garanteed that there won't be any errors in the assembly.



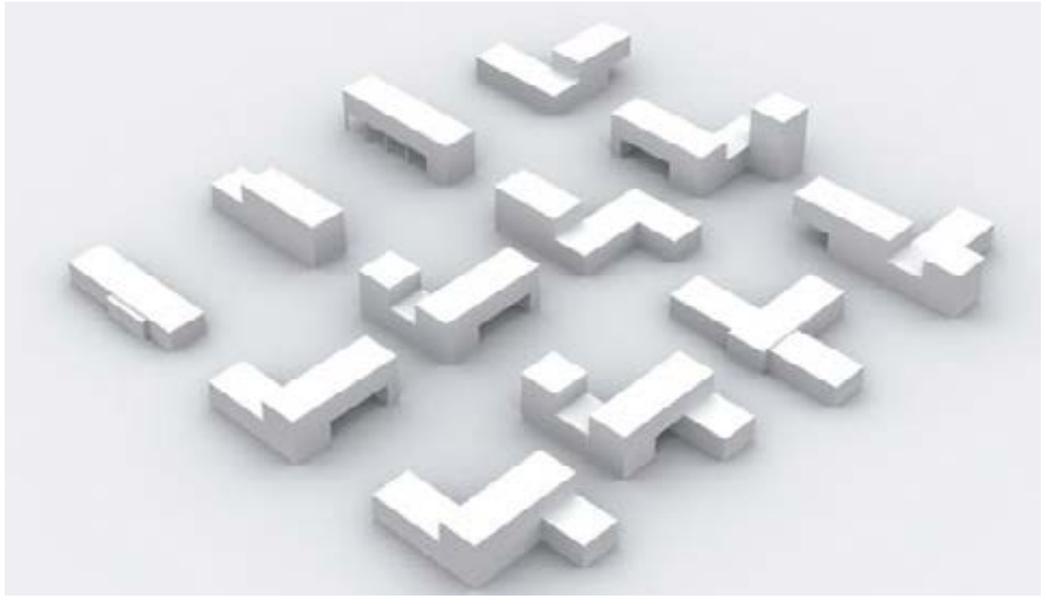






Conclusion

Our society needs innovative solutions for the every day life to handle the lack of available space due to a growing population. 6.5% of all humans are alive right now although the size of our planet stays the same. Therefore innovation in this context stands for space saving products to improve the quality of our homes, work or public places. Additionally the ideal space saving object is not only economic in it's range but also in it's use which implys multi-functionality. The keyword for this purpose is modularity. The meaning of the word may variate in the different sectors where it’s used. Generalised in design an object is modular when it's elements can be split up and assigned to modules according to a formal plan. [1] "Split up" in this context is figuratively as modularisation can also include splitting up a function and reassemble it into another function.



3D modeled modular furniture concept
Source: http://www.arch2o.com/language-modular-architecture/

1 Baldwin, Carliss Y. and Clark, Kim B.: Design Rules, Volume 1, The Power of Modularity, Stanford University, 12.01.2001, p. 5

To achieve the needed modularity and consequently the needed innovation, designers and architects must use their modern resources and benefit from our developped technologies.
CAD and CAE programs both already play their significant rule in the modern design process although especially CAE programs still don't get enough attention of designers when it's not all about technical objects. In the car industry or other similar fields CAE is an inevitable instrument to accomplish the requests of a product. Nevertheless in products of our daily life, like tools or furniture, CAE programs aren't a natural consequence. However when we speak of needed innovation, modularity and the lack of space, product designers must start using CAD and CAE programs like their colleagues in the industrial fields do.
Of course it is uncontroversial that CAD and CAE don't cause modularity or innovation but it is a fact that using those modern techniques does not only save time during the design process but also during the manufacturing.
Therefore in this paper the words "interference checking" are an alligory for "computer-optimised design".
Besides the generally applying design strategies computer-optimised design increases the outcome of productivity immensely because several mistakes in the product can be discovered earlier and not latest in the manufacturing process. The consequence is a reliable, stable, well processed and long-lasting product.
Furthermore the amount of costs in the production are decreased and as a consequence a product not only gets more affordable for the consumer but will also increase the price-performance ratio of the manufacturer without disregarding the actual quality of the product.

A modular sofa
Source: http://www.decorationcentre.com/modular-furniture/

Lounge in a Box: Modular Living Room Furniture Collection by Dornob
Source: http://dornob.com/lounge-in-a-box-modular-living-room-furniture-collection/

Conclusion

So CAE programs offer more possibilites for optimisation and certain analysis test or elements. Therefore CAE may be seen as an addition to CAD. Where CAD prepares the way for an object to be created and realized, CAE makes sure that the after following manufacturing and also usage processes conducted by the consumer will proceed without issues.
Simulating certain stress situation for the material in conncection of the designed shape of the product is only a small part of what other analysis CAE can do.
Summing up CAD is about creation and generation of the 3D model (Design). CAE is about testing its characteristics (Material, strength, fatigue…) using engineering methods.
On account of this it is inevitable to say that computer-optimised design is indispensable and even more than necessary for innovative design. To achieve modularity and consequently innovation we need to common the use of interference checking and consequently extend the knowledge of computer-aided design and engineering softwares. Design processes must be revolutionised and the term "computer-optimised" should be standard in modern product design.
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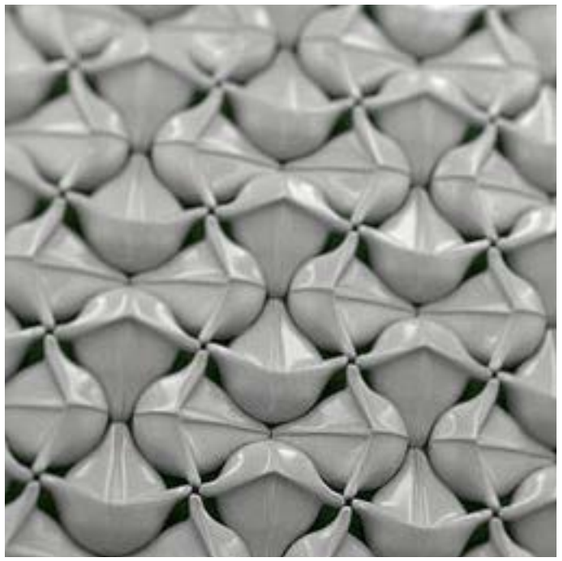
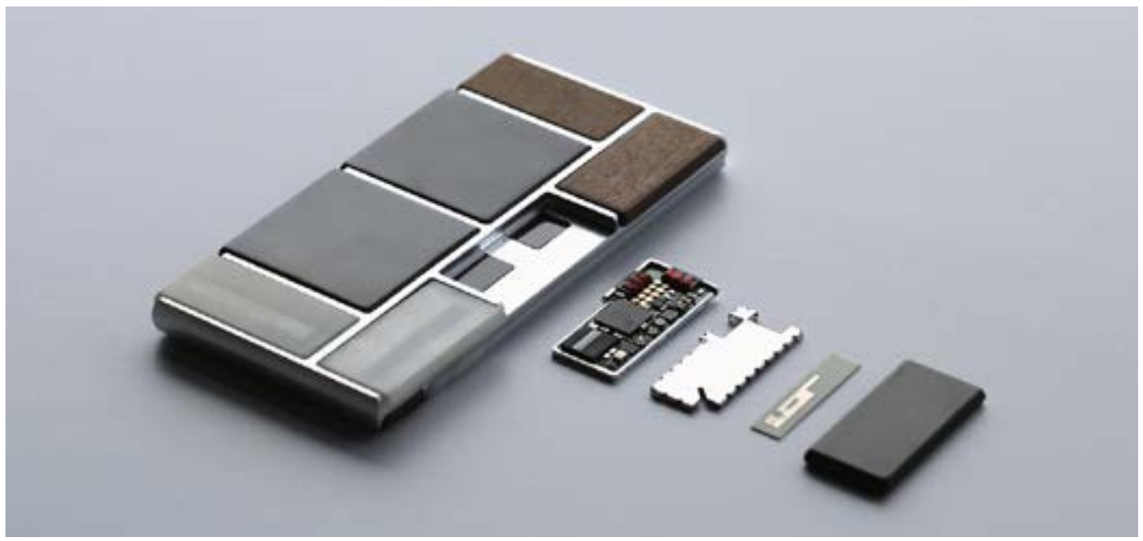


Modularity has many faces: Modular porcelain
Source: https://www.behance.net/gallery/182215/Porcelain-modular-design-mixed

Rendering of a design concept: E-Rope modular power strip by Chul Min Kang and Sung Hun Lim
Source: http://gizmodo.com/185733/design-concept-e-rope-modular-power-strip

Concept of the Flex SmartWatch that features modularity
Source: http://www.techeblog.com/index.php/tech-gadget/flex-smartwatch-transforms-features-modular-design-can-also-be-used-as-smartphone



Phonebloks: A modular smartphone
Source: http://seattlecentralnewmedia.com/cavagnaro/2015/01/22/modular-design-and-project-ara/

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Abhishek C. Lad, A.S.Rao; International Journal of Emerging Engineering Research and Technology ; Volume 2, Issue 7, October 2014

Baldwin, Carliss Y. and Clark, Kim B.: Design Rules, Volume 1, The Power of Modularity, Stanford University, 12.01.2001

John K.Gershenson, G. Jagannath Prasad; International Journal of Agile Manufacturing, Volume 1, Issue 1; Modularity in product design for manufacturability;August 1997

Lincoln Laboratory Journal 19”Looking Back: The TX-2 Computer and Sketchpad 82”

Lincoln Writer, Scopewriter Weisberg, David E. The Engineering Design Revolution

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