Co-funded by the
Erasmus+ Programme
of the European Union

3D modeling and reverse engineering

Purpose of the module:

Modeling

The aim is to introduce an important part of the design process – digital model creation. Understand how the design process has developed and how nowadays products are created in the design process.

Introduction to 3D CAD software

To create an understanding of the possibilities to use 3D content in mechanical engineering and metalworking and other industries.

Reverse engineering – 3D scanning

The aim is to raise an understanding of how 3D scanning can be used for engineering.

3D in industries

Knows where 3D modelling is used (machine building, Mechanics /Simulation, civil engineering, animation and games, geology and medicine etc.)
A pupil is aware at a basic level of design automation

Achievable results/ learning outcomes:

Modeling

A pupil is introduced to the development of design from civil engineering and metalworking perspective.

*Introduced to prototyping in the car industry.*A pupil has an understanding and knows the difference between 2D drawing and 3D modelling. Understands basic geometrical shapes that are used in 3D modelling. A pupil is aware of the main steps in the design process. A pupil can explain how product design is made nowadays. Knows the term reverse engineering and can give an example of it. Knows what a technical drawing and its contents are.

Introduction to 3D CAD software

Knows the term Digital twin.

Knows about MBD (model-based definition – 3D PDF and so on).
A pupil has awareness about 3D space where 3D content is created (space, planes, axes, coordinate system).

The pupil knows basic actions in 3D modelling and has tried basic steps – sketch (line, circle etc.), and has created basic forms with functions like extrude, cut, and revolve functions.

Knows about needed information to create a model (dimensions, constraints, material, interactions).

Knows basic 3D model elements – sketch, part and assemblies and resulting drawing.

Reverse engineering – 3D scanning

A pupil knows what 3D scanning is.

Knows some applications of this method.

A pupil knows what is meant by reverse engineering.

3D in industries

Knows where 3D modelling is used (machine building, Mechanics /Simulation, civil engineering, animation and games, geology and medicine etc.)
A pupil is aware at a basic level of design automation

Tasks

Modelling

1. Show the engineering process from concept (idea) to product modelling in stages.

2. Talk about projections

Make 2D drawings or sketches and 3D hand sketches of the simple body (*phone, round wall watch, cylinder etc*), taking measurements before. Then try to change the design of the body.

3. Watch a demonstration or build a 3D model practically. Then make changes to the designed body.

4. Compare two ways of design modelling, and talk about the differences in both methods.

Introduction to 3D CAD software

Tell about used terms and geometric figures used for 3D modelling.
If possible, practically build a 3D model, an assembly and a drawing or demonstrate steps and processes.
Use dimensions to parametrically control the model.

Create your 3D content – a digital twin of products on available platforms.

Create a 3D digital representation (digital twin) of the product.

Create a simple part and assembly from parts.

Create a basic drawing for the part.

Explain basic elements in 3D modelling – parts and assemblies and interaction.

Show/talk about resulting documents after 3D modelling.

Reverse engineering – 3D scanning

Explain 3D scanning and reverse engineering.

3D Scanning applications.

3D in industries

Present several 3D models using examples from different industries.

Tell about large-scale design automation, and how automation helps speed up the production process.

Length of module

1 academic lecture intro and 2 – 3 practical lessons

Name of learning subject in which module can be used:

Main subject **Technology and design**, but can relate to mathematics, physics, arts, connects in social subjects' topics about production, foreign language – mostly English, but others available too.

Themes of the module

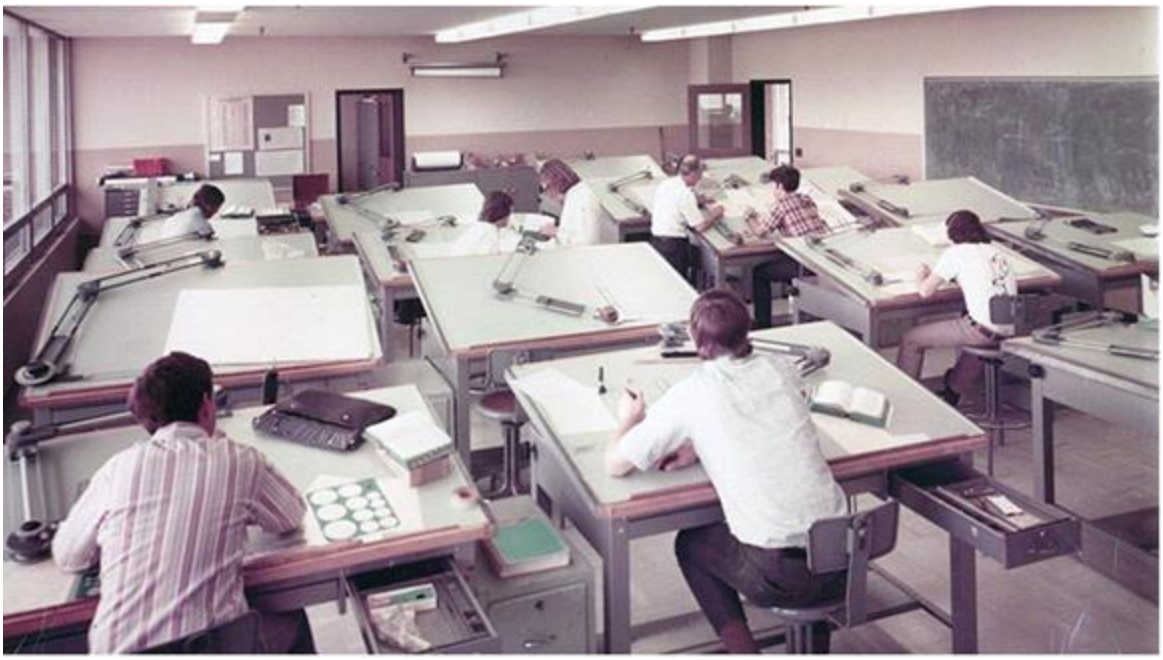
1. Modelling in design
2. Introduction to 3D CAD software
3. Reverse engineering – 3D scanning
4. 3D in industries

3D modelling in our world has various applications, you probably have seen 3D rendered pictures and even movies, or you have played games where 3D technologies are a core element, similarly, our surrounding is created by engineers who use 3D modelling for the design process, these can be small everyday things or even buildings and city infrastructure, nowadays almost everything is before production designed by using 3D modelling. This allows for evaluating

results already in the design stage and changes can be brought in instantly even physical testing can be done by using a digital twin of the end product and trying it out in Simulation programs where it is possible to apply physical interactions.

It was not so earlier before age of powerful computers, engineers did their design process by drawing on paper 2D representations of the design and then we're copying drawings for all needed instances to get the product produced. In many ways it was more human resources demanding processes than it is nowadays, more people were needed to do the amount that one person does today with CAD (computer-aided design), this job was partly done by engineers, but the main drafting work took lower qualified staff - draft specialists. Some people did engineering work some did drawing.

source: https://en.wikipedia.org/wiki/Drawing_board



Source: https://www.boredpanda.com/vintage-photos-life-before-autocad/

In the pictures above can be seen how engineers worked before the computer age actually at that time this process was divided into more levels – some engineers and drawers did do the main part of the paperwork.

Around 1960 first CAD software was presented, this allowed to do the same 2D drawing only on the computer screen, this eliminated need for some amount of work, made work easier, drawings could now be printed, and the best is that editing and design changes could be done much easier and faster, no need to redraw and copy by hand stacks of paper. But still, engineers and draftsmen were needed to create 2D projections of 3D real-life parts and the assemblies of the whole design.

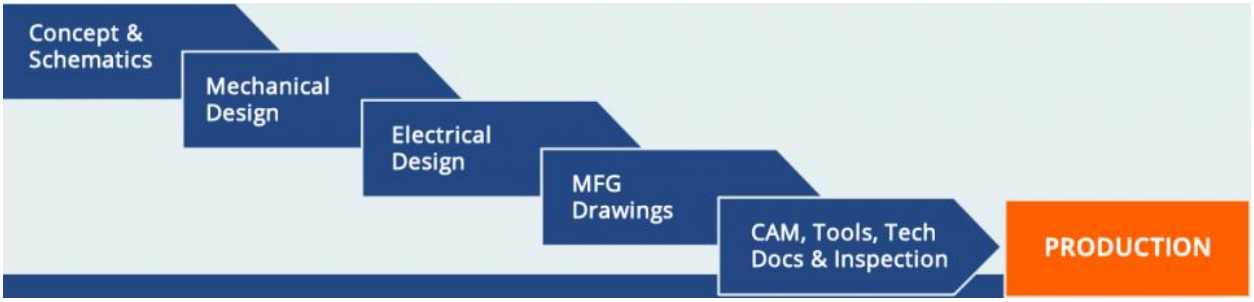
In the nineties of the last century, following change started, computers got more powerful and available, and software companies started to offer CAD that was able to model 3D design. This could be called switching from 2D to 3D.

Interesting time representation of engineering CAD software timeline: https://partsolutions.com/60-years-of-cad-infographic-the-history-of-cad-since-1957/

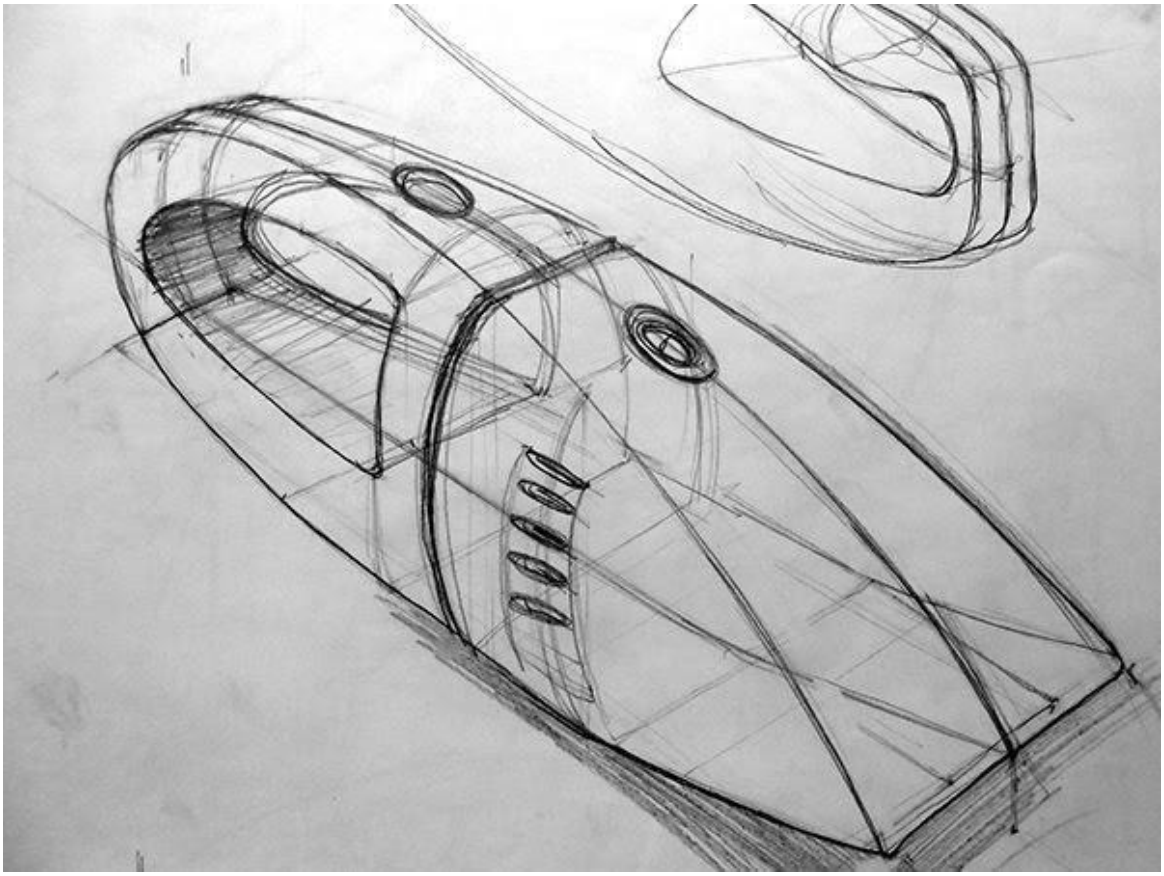
3D solutions developed and already around the year 2000 they became the main engineering solution in many companies. With that, all engineers' work became fewer man-hours demanding and things that previously were done by many workers now are done on the computer by fewer engineers. And paperwork has become more automated and currently we can see a shift where engineering documentation is no anymore printed but all product manufacturing information is stored and managed electronically it is called MBD (model-based definition).

Let us look a little bit into the engineering process to understand what is done in the design process:

Depending on the industry (household, medical, rural, civil, aerospace engineering or other), where we would like to design a product we need to do certain steps, like:

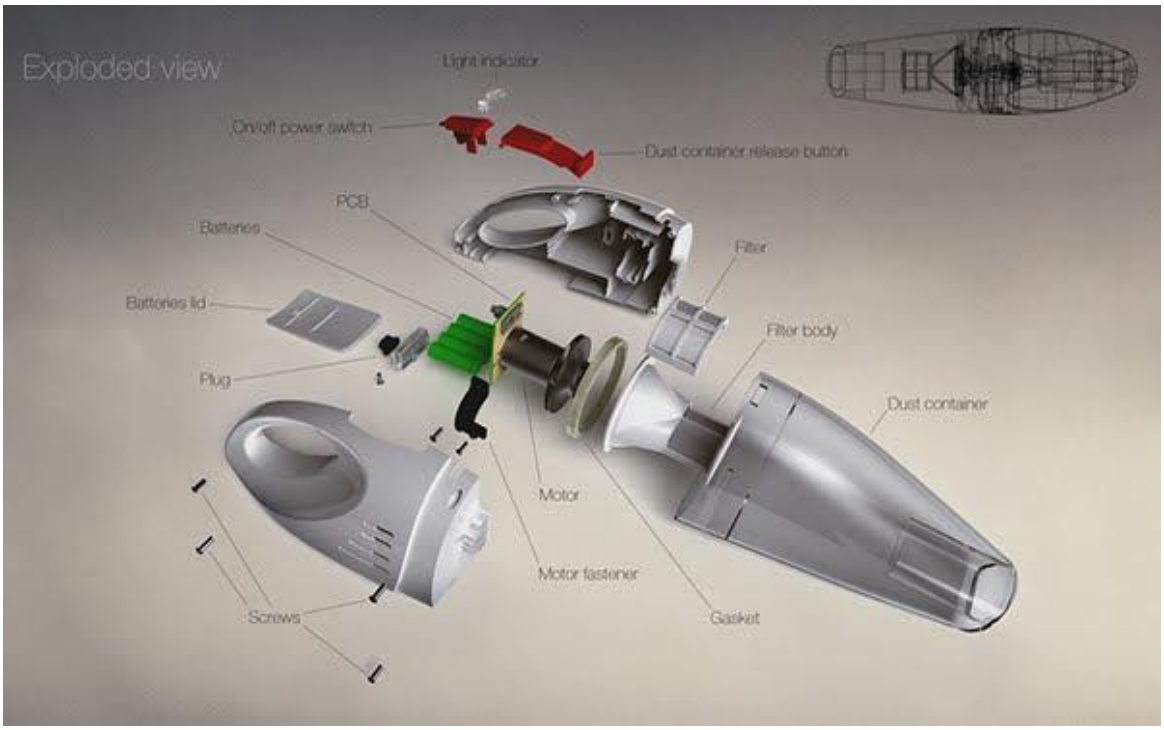


Concept design - where the product is defined by its properties and tasks, especially if the exterior is important then concept sketches are made



https://www.behance.net/gallery/10219359/3D-product-sketches

Detailing - next step is done by engineers who will use their knowledge to design end-products 3D models of parts which will be joined into assemblies, we can say that their first part of work is to create a digital twin of the intended product, do the simulation on it and create documentation for the production. For an example see below exploded 3D model of a small hand vacuum cleaner.



https://www.behance.net/gallery/12471947/Argos-handheld-vacuum-cleaner

Production - from in previous steps designed product documentation production process is prepared and the end product is produced and is ready to be delivered. Of course, production is not so easy, for mass production machines, moulds and other equipment should be designed which is again done by engineers using 3D modelling.

Besides previous steps, marketing materials or even sales processes can be started while the product exists only in digital form since good 3D model renderings can be created and information communicated to prospects.

Let's look at one product chain that has a lot of 3D modelling involved and what ensures our modern life is in one or another way produced - for example, basic things like bread – from technical sight what is involved in the process from the grain to bread on the table at home? *(Could be some brainstorming in the classroom or substitute with different product and create group tasks to think wider about what is needed for some product production)*

If we start with a grain (seed), it should be planted, nowadays it is done with a machine, then when the plant grows it should be harvested, grains should be separated from the plant and so on, then milled into flour and in bakery backed, then brought to the shop and your table.

The thing that should be understood is that at each process many machines or things that are produced by the metalworking industry are involved: seeder, combine harvester, close where the grains are stored, then the flour mill, solution for delivery to the factory, backing machines like mixing and ovens, even shelves in the shop etc. production and if we look even wider, then instruments and machines to produce these machines are engineered and designed beforehand

too. For an illustrative description look at the pictures below. With that, I would like to say, that engineering and surrounding specialists do substitute a big part of our comfortable living in this current world and if you don't have the opportunity to see it or understand it, you can not imagine how interesting is the design process.

For teachers: (Maybe even need to tell that engineering and design process is not shown in TV and shown in resources that youth uses, that's why they don't have an understanding that this could be one more way of living.)

© CanStockPhoto.com - csp56815359

In the same way, we can look at other everyday use products – what is needed to get to the end-product from production and what is needed to create production.

We can conclude that for average production we need not only to design products but design production itself, machines conveyor lines, and devices that do a specific job.

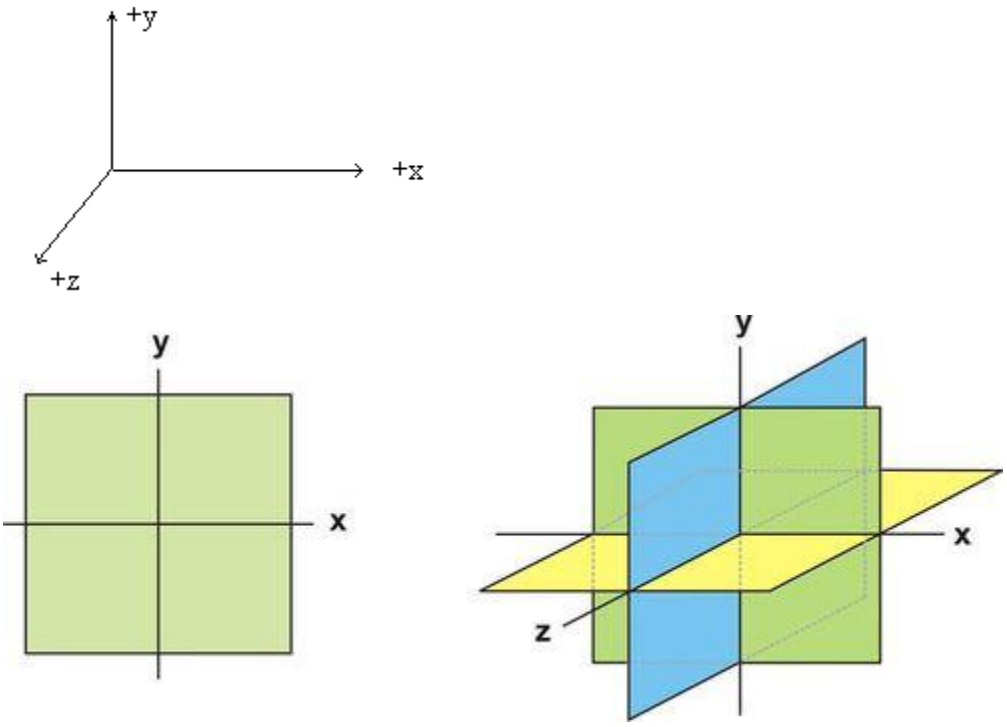
But if we limit it to some product that consists of at least a few parts we need to have an idea how it will look like, we need to know what tasks it should do and ideally, we should know what forces it should withstand, but this can be determined in the development process too.

Basic in 3D modelling

Let's look at 3D modelling practical aspects and basics:

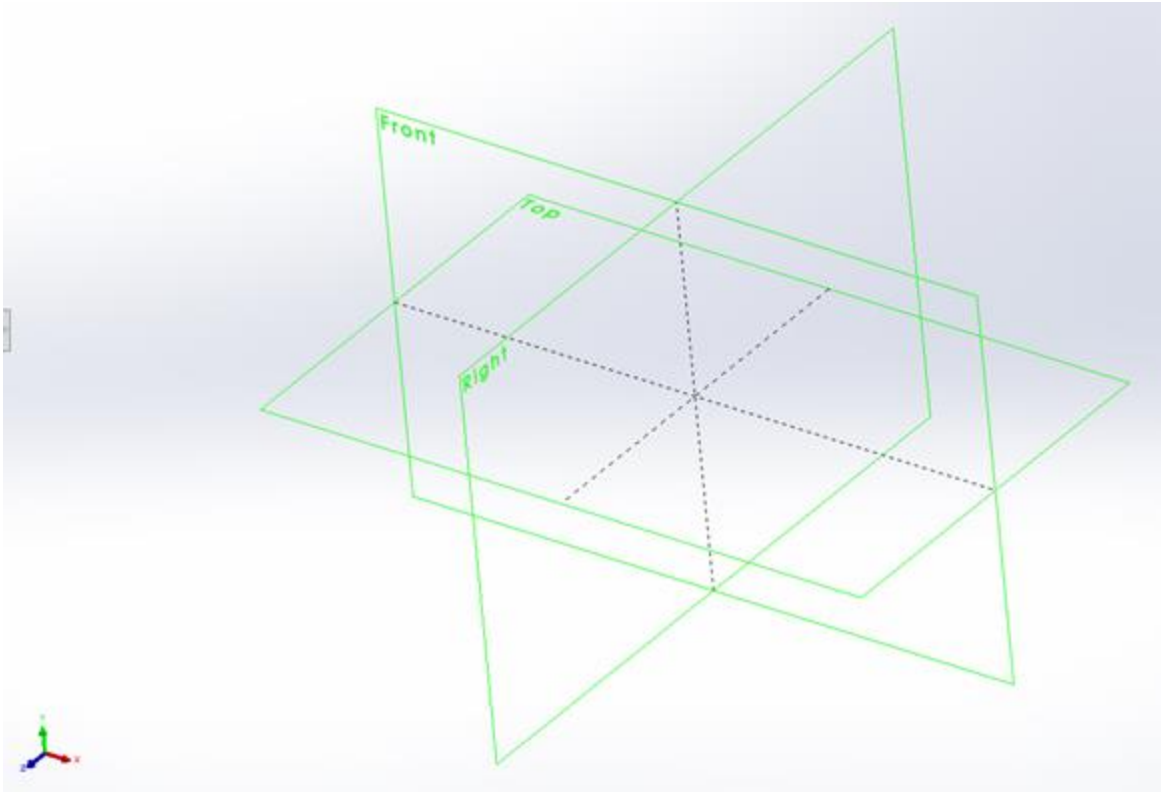
First that we should understand is 3D space – space where we will model our first part and at the end full assembly of the product.

As you maybe already have guessed 3D stands for 3 dimensions, these are the basics, that describe our space – most of the time 3D is described by 3 axes X, Y and Z as you probably have seen in some parts of mathematics.



Source: https://www.ck12.org/na/3d-coordinate-axes-and-coordinate-planes-in-three-dimensional-space-1/lesson/Coordinate-Axes-and-Coordinate-Planes-in-Three-Dimensional-Space-xi-maths/

The same 3 axes determine the space and position of the next important entities – planes. Planes are used to easier perceive the given 3D space more and orient the model and in many cases are used as a place for the first sketch. And from the model view perspective determine the orientation of model views like the Top, Front and Right views.



And final important entity of our 3D space is the origin, the point that is in zero coordinate, many times used as a main coordinate reference for each of the directions and is widely used in dimensioning.

If we go further, then we can start to talk about our first part. In most 3D modelling software 3D shape starts from a 2D sketch which we turn in the 3D body (volume) and step by step adjust to our *Design intent*. But other software uses primitives like a plane, cube cylinder and sphere as initial geometry and then forms it to the intended geometry.
In the example below, we will look at the method which is used in most engineering software - where design is started from a sketch. When we have understood what we model, then we need to think from what shape we can easier develop the shape of our part – this will determine what shape we should sketch first.

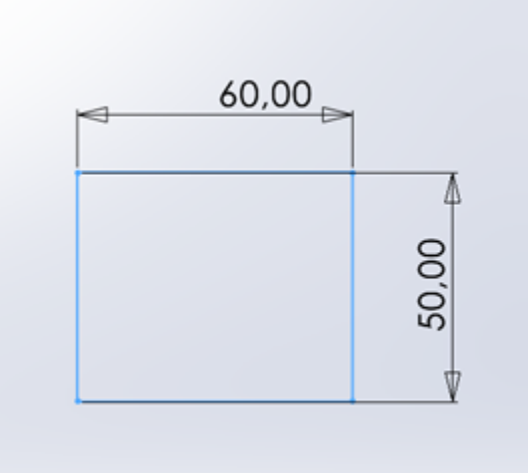
For example, if we need a cylindric part then the first sketched line should be a circle with defined dimensions.

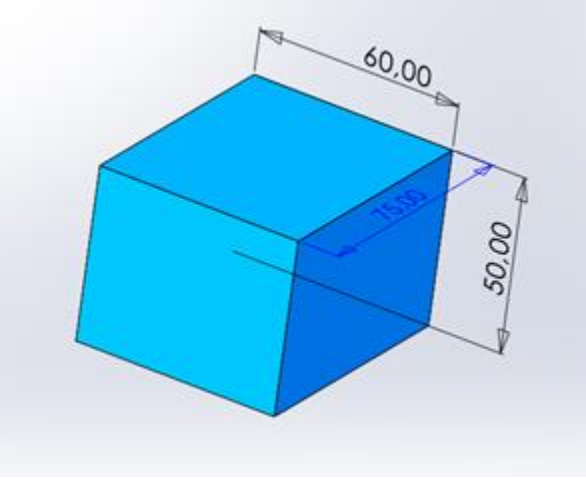
Here we come to the sketch elements and the main ones are:

- Line
- Circle
- Rectangle

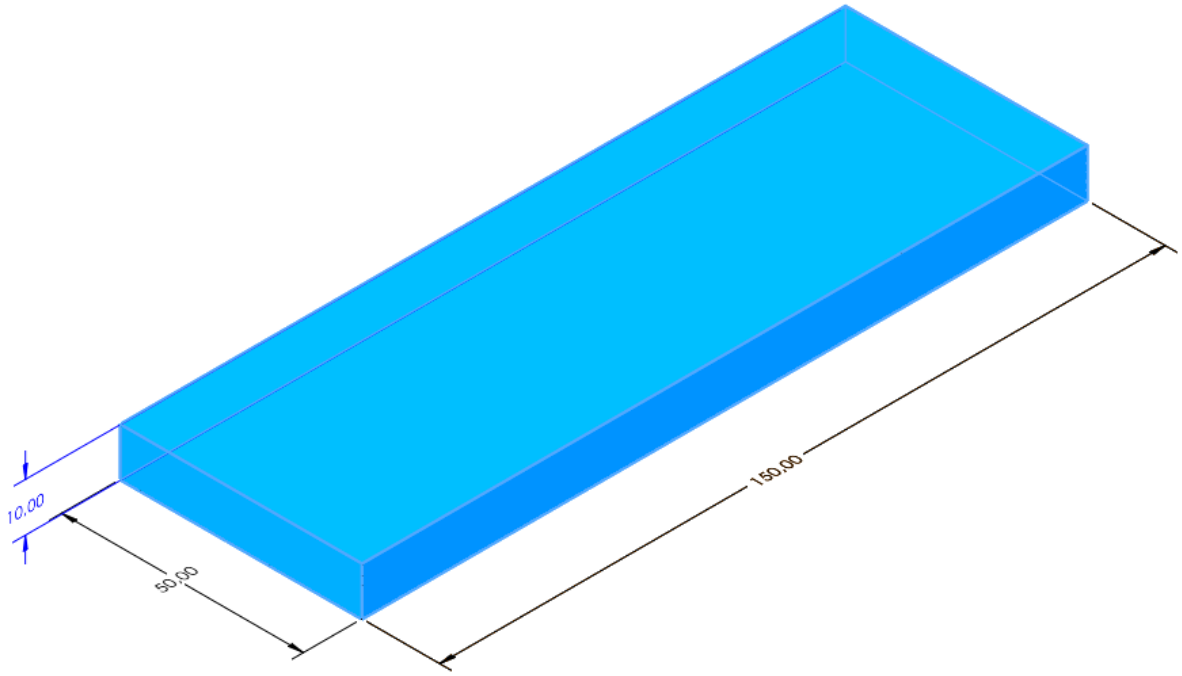
- Polygon
- Spline
- Other entities are developed from these basics to ease work.

When we have thought of our Design intent, we should decide what form will be that we need to create a part, this determines what we sketch and afterwards with help of feature extrude some shape.





From a simple plate, step by step we can develop part.

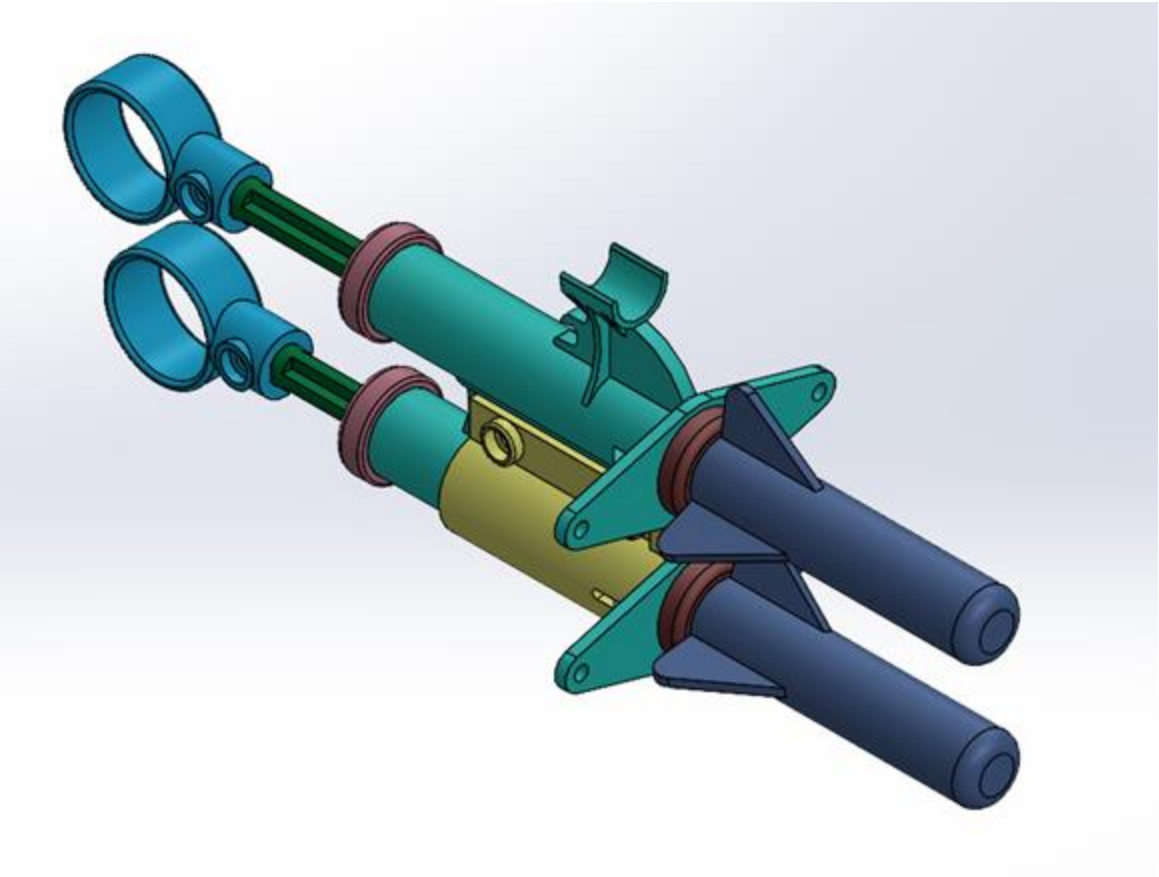


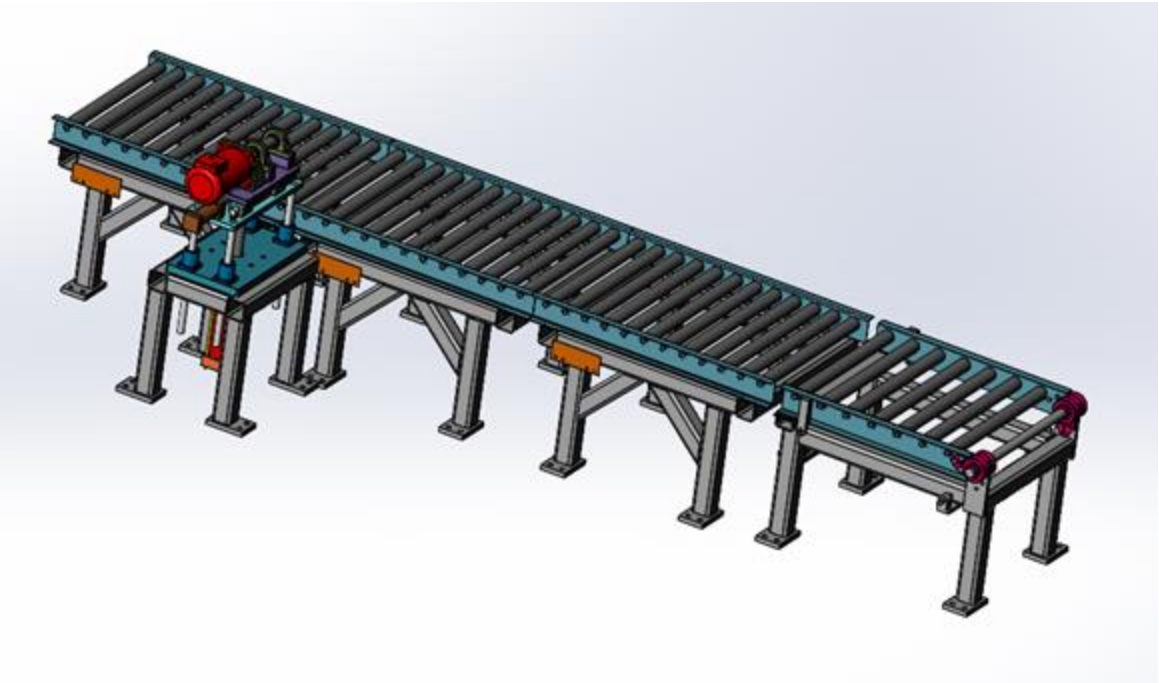
VIDEO (Simple first part)

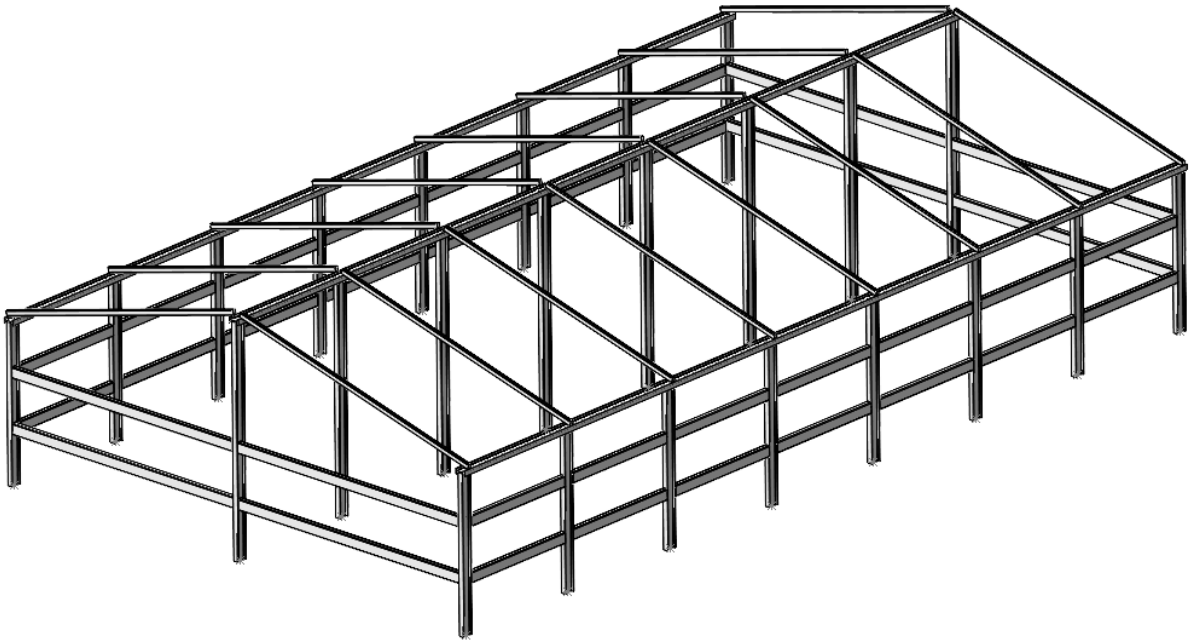
Shapes then get extruded from sketches and edited till the design intent of a part is reached. Parts then get put together into assemblies; methods can vary. For production real benefit is to virtually assemble the product, and see how everything fits together. If some parts overlap or need to be adjusted for assembling. In the end, virtual simulation is possible in many software solutions to determine if the product in such a version will be able to withstand intended loads or if it will serve the warranty period.

VIDEO (Example of an assembly)

Some 3D modelling example pictures:







In mechanical engineering standard software and at the same time most popular 3D modelling software is Solidworks, AutoCAD, Autodesk Inventor and Fusion360, SolidEdge and CATIA, but these all are costly professional use software. For school and education purposes is better to use free or not so-expensive solutions, like:

- ✔ **Solidworks Apps for Kids** – for free, lessons and instructions are available, the classroom solution is in beta testing, and the solution includes design capturing, modelling, mechanics, visualization and the possibility to save geometry for 3D printing. Works in all popular web browsers, touch device friendly - https://www.swappsforkids.com/

- ✔ Autodesk Thinkercad – for free, lessons available for classroom or self-study available - https://www.tinkercad.com/lessonplans

- ✔ **Blender** - free and with a wide community and free learning resources on-site and on youtube, animations can be made - www.blender.org

- ✔ SketchUp – https://www.sketchup.com/products/sketchup-for-schools

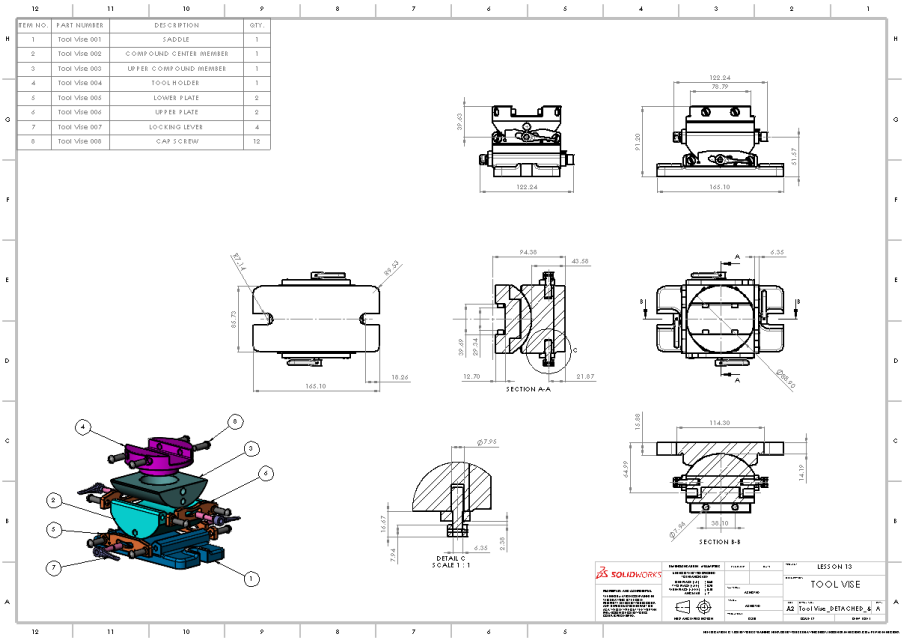
- ✔ Onshape – free for students and educators - www.onshape.com

- ✔ Fusion360 - free for students and educators

- ✔ Leopoly Maker

** Most of the above-mentioned software solutions will allow you to save your creations to 3d printable format and you will be able to produce your design.*

Engineers every day is like connecting the dots, he has learned in school, his special field many times he learns by doing, he knows how to search and evaluate similar products or find usable components. And then the main design process, creating elements and then connecting everything into the assembly. Here we can talk about a digital twin of the end product. Which can be tested in computer simulations to avoid repeated design after the prototype is produced. But from the end assembly engineer needs to create documentation for production needs, which we call drawings. With 3D modelling software, this is much easier than it was by hand drawing. Many times drawing is the design end process, but still very important because is used almost as a language for communication with people who will read it and create already not virtual, but the real product.



Drawing is one way how to communicate the design to the customer or production, but since we have a 3D model of each part and assembly, we can use these files directly in production where the 3D model can be directly loaded into a CNC milling or tunning machine. Of course, the same 3D model can be used for other production methods, for example, various 3D printing methods. The main benefit of direct use of a 3D model compared to communication with a 2D drawing is time-saving in the process where a CNC engineer needs to redraw the 3D model in his solution for production.

Working environment

The working environment of an engineer who works on a design is an office with work at the desk and the main instrument is a powerful computer with some dedicated software for his design field. Of course, visits to the production site are welcome, to better see and understand production issues and finding of solutions for upgrades.

Education

The best way to become an engineer is to choose a technical path already at the end of elementary school when you can go to vocational education school where you will get together with secondary school content learn specialization in the chosen direction and at the of school you will have already profession with which you will be able already to find a paid job, but of course, you will be able to continue education in a higher education institution where your vocational school's experience will be very useful to become an engineer.

After secondary school or gymnasium, you can go to higher education institutions like colleges or universities and become an engineer. Engineering as a profession is well paid and with a guarantee, that if you choose this path for your life, it will be an interesting and challenging lifetime occupation.

Here is a list of schools where you can become a mechanical engineer:
(Should be adjusted by specific country)

Other uses of 3D modelling:

One of the most common other use of 3D modelling in civil engineering was a very long time staying in the 2D world but nowadays it is agreed that the 3rd axis perspective gives a more detailed view of the building and is faster understandable for involved personnel. The building can be split into layers like construction elements, communications solutions, electricity and water supply, doors windows, furniture and so on, where each involved specialist can look at his important information. Civil engineering includes roads too, where you need to understand what lies beneath the road and plan the layers of it and this all can be designed in 3D.

Electrical engineering many times still in flat 2D design, but more and more engineers are using solutions that allow not only to plan electric circuits in a flat space but do the routing and setting of the components in 3D.

A big and alternative to the previous is the entertainment industry which uses 3D modelling for creating imaginary scenes for video games, animations, even movies and cartoons. Many times with help of software modelled characters are moved by real humans, but now more often everything is created as a simulation. By the way, the above-mentioned software - Blender allows the creation of cartoon-like 3D animations too.

One more example could be tailoring could be again a variety of products that can be designed in the computer and then sent for production, it could be your clothes, shoes, but at the same time,

car seat or sofas fabric can be designed in the computer and then cut with the laser cutter and then sewn.

Nowadays even chemistry and life science processes can be modelled in 3D with specially designed software, for example, magnetic resonance imaging gets a 3D model of the human body and then doctors can understand what is happening and if there is a problem, of course, is not so much as modelling but in a good way leads us to the next topic digital and 3D imagining.

Reverse engineering and 3D scanning

In real life productions, there are cases when you already have some product or solution, and it is needed to recreate it, there could be many reasons for that, for example:

· for improvements,

· maybe no original design information available, for example, a car from the beginning of the previous century that needs some broken part for replacement,

· or you need to add something to an existing solution, for example, some motor to an existing frame in the factory, or to pair aggregates like gearbox and engine in a rally car,

· sometimes even to “steal” a good design from a competitor,

· in production 3D scanning is used for quality control, to measure if the produced result is as expected.

As with all technologies methods of reverse engineering has evolved together with computers and measuring techniques. Reverse engineering is a process where an already existing product is disassembled and recreated for further production or improvement.

Methods where the solution is recreated from photos, sketches on the paper sheet, direct measurements of products, up to precise 3D scanning and exact 3D measurements.

Interesting resource on measurement history: https://www.creaform3d.com/blog//the-history-of-metrology-from-galileo-to-optical-systems/

For simple raw and basic measurements ruler or measuring tape can be used, for more precise calliper and micrometre. In production for measurements and quality checks, today used electronic instruments that can be used to measure in 3D space, like measuring arms - coordinate measuring machines (CMMs), are used in a controlled environment mostly used for precise measurements and quality checking in production.

But most modern solutions are non-contact solutions, that can turn an image into a 3D model.


The scanned result is loaded into software where it can be processed and turned into a 3D object and then used depending on the purpose.

Same way as with 3D modelling 3D scanning has other purposes too, maybe the main imaging technique can differ but almost always the result is a 3D model. This can be used in the entertainment industry to create models of actors, maybe to mimic human body movements, or there are video games that by using similar techniques follow your body movement and include it into the game, especially interesting when virtual reality or augmented reality is used. But in some way, it can be used in healthcare with special solutions to understand medical issues more deeply without intrusion into the body.

Fun thing is that you already can scan 3D scan with your smartphone, search for an example in your app store for a 3D scanner. It will look like this:

VIDEO https://youtu.be/jyfktD1CtLM or similar

In the same way, small things are getting scanned – astrophotography and aerolaser scanning - big things, like our Earth or country institutions do scan the country surface to get precise data on land relief or even measure the number of trees in the woods, depths waters and other applications, these scans are done from planes or even satellites.

Latvijas Ģeotelpiskās informācijas aģentūra

Daugavas loki

(part of river Daugava in Latvia)

Cēsu pilsētas 3D modelis

(3D model of city Cēsis in Latvia) https://www.lgia.gov.lv/en

Professions and education.
Professions in which computer modelling is used are usually highly valued by professionals and well paid. Skills can be acquired at different levels both in technical colleges and in further education in higher education institutions by becoming engineers if engineering is the topic. As mentioned before other fields of use exist too.

(Professional schools should be collected country depended.)

Tasks for classroom or homework:

(in schools chosen software)
1. Model a simple part, and try to stick it together with another part to create an assembly.

2. If this is group work, then the group can agree to a product that they design, make a plan sketch on paper of needed elements and then each person can create one or two parts in 3D modelling software and then put it into assembly (does not need to be A-Z product, some simple element group of bigger assembly. If more groups then all can create a whole product – line engineering divisions in the bigger company would do).

3. If a 3D printer is available, then it is useful to create some simple but useful geometry for printing, for example, a hanger for a coat, or some toy.

4. In engineering some time of the design process is spent on searching for analogue ideas and copied if possible. Try to search the internet for 3D content and you will find ready 3D models for printing or use in 3D modelling software. Find one printable model and one component that could be useful in 3D engineering (screw, bearing, engine, hinge, wheel or what comes to your mind).

5. Search the internet for 3D models for 3D printing

Questions for the test

What was the computer-aided design technique used before 3D modelling got available?

a) 2D modelling

b) 1D modelling

c) Mathematics

Comment: before computers and their software evolved there was 2D modelling available, a process that is very similar to drawing on paper but done only on the computer.

How many axes (directions) are used in 3D modelling?

a) 1

b) 3

c) 2

Comment: 3D stands for the number of dimensions used, so it is 3 dimensions, mostly described as X, Y and Z axes

In which industries 3D modelling is used?

(free answer field)

Which are the basic elements of the 3D modelling environment?

a) Earth centre, Sun position, Horizon

b) Origin, XYZ axes and planes between axes

c) Radius, perimeter and area

Comment: there could be cases where a coordinate system is chosen planets or even galaxies, but for common CAD 3D modelling main references are used - origin or point of the zero coordinate and 3 perpendicular axes are used and between each pair of axes a plane is formed.

What is reverse engineering?

Open question /own words - Answer- when an existing part/product is copied, its detail is created so that it can be produced

How the 2D document that describes the design intent of the product is called?

a) Painting

b) Drawing

c) Sketch

Correct- b) Drawing

In what units size of the design defined?

correct answers: mm, millimetres, cm, centimetres, meters, m, in, inch

Name basic elements of sketching (at least two)?

Correct answers: line, circle, rectangle, polygon, spline

Can 3D scanning be used for production quality control?

Yes / No

Correct answer-yes

Can 3D models be used directly in production?

Yes/No

Correct answer-yes

Is special education needed to become a mechanical engineer?

Yes/No

Correct answer-yes

Can household goods be modelled in a 3Dmodelling program?

Yes/No

Correct answer-yes

Is 3D modelling an activity before 3D printing?

Yes/No

Correct answer-yes

How Many Millimeters are in one meter?

10, 100, 1000

Correct answer- 1000

Where is 3D scanning used?

o to make improvements to an existing product

o when it is necessary to recreate a damaged part

o if it is necessary to combine existing elements, for example, to combine an engine from one manufacturer with a gearbox from another manufacturer

o to steal an existing product from a competitor

Correct answer-all answers

Additional resources:

Free CAD https://all3dp.com/1/best-free-cad-software-2d-3d-cad-programs-design/

Modelling fundamentals https://youtu.be/tTfIo_bezqw

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5. Find a 3D scanning application for a smartphone and scan a 3D object.

Questions for the test

What computer-aided design technique was used before 3D modelling got available?

a) 2D modelling

b) 1D modelling

c) Mathematics

Comment: before computers and their software evolved there was 2D modelling available, a process that is very similar to drawing on paper but done only on the computer.

How many axes (directions) are used in 3D modelling?

a) 1

b) 3

c) 2

Answer: 3D stands for the number of dimensions used, so it is 3 dimensions, mostly described as X, Y and Z axes

What industries 3D modelling is used?

(free/open answer field)

Which are the basic elements of the 3D modelling environment?

a) Earth centre, Sun position, Horizon

b) Origin, XYZ axes and planes between axes

c) Radius, perimeter and area

Answer: there could be cases where a coordinate system is chosen planets or even galaxies, but for common CAD 3D modelling main references are used - origin or point of the zero coordinate and 3 perpendicular axes are used and between each pair of axes a plane is formed.

What is reverse engineering?

Open question /own words - Answer- when an existing part/product is copied, its detail is created so that it can be produced

How the 2D document that describes the design intent of the product is called?

a) Painting

b) Drawing

c) Sketch

Correct- b) Drawing

In what unit's size of the design defined?

Correct answers: mm, millimeters, cm, centimeters, meters, m, in, inch

Name basic elements of sketching (at least two)?

Correct answers: line, circle, rectangle, polygon, spline

Can 3D models be sent directly to production?

Yes / No

Correct answer-yes

Is special education needed to become a mechanical engineer?

Yes / No

Correct answer-yes

Can household goods be designed in a 3D modelling environment?

Yes / No

Correct answer-yes

Is it possible to create movies with the use of 3D modelling?

Yes / No

Correct answer-yes

Is the 3D modelling pre-process for 3D printing?

Yes / No

Correct answer-yes

How Many Millimeters are in one meter?

10, 100, 1000

Correct answer- 1000

Where is 3D scanning used?

o to make improvements to an existing product

o when it is necessary to recreate a damaged part

o if it is necessary to combine existing elements, for example, to combine an engine from one manufacturer with a gearbox from another manufacturer

o to steal an existing product from a competitor

Correct answer-all answers

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