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T3 Modelling

3.4 Computer-Aided Design (CAD)

Concepts and principles:
• Types of CAD software
• Surface and solid models
• Data modelling including statistical modelling
• Virtual prototyping
• Bottom-up and top-down modelling
• Digital humans: motion capture, haptic technology, virtual reality (VR), and animation
• Finite element analysis (FEA)

Essential Understanding:
• Advantages and disadvantages of using computer-aided modelling
• How data models structure data through database models
• Design of information systems to enable the exchange data
• How haptic technology, motion capture, VR and animation can be used to simulate design scenarios and contexts
• Comparison of FEA with testing physical models
• Use of FEA systems when designing and developing products

Nature of design:
As technologies improve and the software becomes more powerful, so do the opportunities for designers to create new and exciting products, services and systems. Greater freedom in customization and personalization of products has a significant impact on the end user. The ability to virtually prototype, visualize and share designs enhances the whole design cycle from data analysis through to final designs.
Types of CAD software
Computer Aided Design, also known as CAD, is a design tool that employs computers to create drawings and models of products while they are in the process of being created. CAD was first created in the early 1960s and today is used to design almost every product on the market in the world. Many types of CAD exist for different applications.

CAD software is used in fashion, product design, automotive, architecture, and engineering.

Task: Watch the video clip about how CAD is used at Dyson.

2D CAD
- Two-dimensional, or 2D, CAD is used to create flat drawings of products and structures. Objects created in 2D CAD are made up of lines, circles, ovals, slots and curves. Among the most popular 2D CAD programs are AutoCAD, CADkey, CADDS 5, CATIA v4, Adobe Illustrator and Medusa.

3D CAD
- Three-dimensional (3D) CAD programs come in a wide variety of types, intended for different applications and levels of detail. Overall, 3D CAD programs create a realistic model of what the design object will look like, allowing designers to solve potential problems earlier and with lower production costs. Some 3D CAD programs include Autodesk Inventor, CoCreate Solid Designer, Pro/Engineer SolidEdge, SolidWorks, Unigraphics NX, Sketchup and VX CAD.
Surface and solid models

Surface models
Surface models are photo-realistic images of a product, offering some machining data but no data about the interior of the product. Surface modelling has no wall thickness.

Task: Click on the image and watch a short video showing surface model software in action. Notice the pulling and pushing of the surfaces to create complex curves.

Solid models
Solid models are clear representations of the final product. They provide a complete set of data for the product to be realized including internal dimensions and volume. Originally developed for machine design, and is used heavily for engineering with large part assemblies, digital testing and rapid prototyping. Solid modelling is defining an object with geometric mass. Solid modeling programs usually create models by creating a base solid and adding or subtracting from it with subsequent features. Features such as extrude, extrude cuts, revolves, radii, chamfers, etc.

Data Modelling
A data model explicitly determines the structure of data or structured data. Typical data models include databases and information systems. Developments in information and communication technology (ICT) make a data model important to applications that use and exchange data. Examples include GPS, 3D Scanning, Digital testing, materials, etc.
Virtual prototyping
Virtual prototyping involves the use of surface and solid modelling to develop photo-realistic interactive models. Virtual prototyping is a method used during product development. It involves using computer-aided design (CAD), computer-automated design (CAutoD) and computer-aided engineering (CAE) software to validate a design before committing to making a physical prototype. This is done by creating (usually 3D) computer generated geometrical shapes (parts) and either combining them into an "assembly" and testing different mechanical motions, fit and function. The assembly or individual parts could be opened in CAE software to simulate the behaviour of the product in the real world. These can also be considered as digital mock-ups.

Task: Watch this video clip and think about the advantages and disadvantages of virtual prototyping. Do some research into other examples of virtual prototyping in action [Google digital mock-ups for better results]

Bottom-up modelling
When designing using a “bottom-up” strategy, the designer creates part geometry independent of the assembly or any other component. Although some design criteria are often established before modelling the part, this information is not shared between models. Once all part models are completed, they are brought together for the first time in the assembly. Requires the designer to draw parts individually and then assemble them together by applying
constraints, such as mate and flush. If possible, placing the components in the order in which they would be assembled in manufacturing.

Unless component parts are drawn to change and adapt, they might not fit the requirements of the design. This can cause problems if perhaps a screw that has been drawn will not fit into the hole and will have to be re-drawn. The process by which the Mars rover Curiosity was created followed a “bottom-up” strategy.

**Top down modelling**

Top-down modelling is a product-development process obtained through 3D, parametric and associated CAD systems. The main feature of this method is that the design originates as a concept and gradually evolves into a complete product consisting of components and sub-assemblies.

Top down modelling begins with the design criteria and create components that meet those criteria. The layout such as the image on the right can be a 3D design created from a single part such as a computer mouse. From this single part, space and walls for batteries, buttons etc can be drawn into the body so it is known that everything fits.

Usually, changing one part can cause changes to several other parts that are adjacent or connected to it, if the designer has set the program to acknowledge them.

The final assembly is a collection of interrelated parts that are uniquely designed to solve the current design problem.

*In reality, any assembly will need to use both techniques, therefore a "hybrid" model, where all the parts and components designed will be modelled top-down and all the purchased components will be "inserted" using bottom-up.*
Digital humans

Digital humans are computer simulations of a variety of mechanical and biological aspects of the human body. They can be used to interact with a virtual prototype. Human simulation in product design enables a product to be developed more quickly, as there can be more design iterations in less time. This results in higher product quality that meets human requirements more accurately. Digital prototypes are cheaper to produce than physical prototypes. Products are safer as a result of more thorough analysis of safety aspects. Improved productivity results from enhanced automation of the development process.

The digital humans can be adjusted to any shape or size. There is a female version called Jill and a male version called Jack.

Digital humans enable manufacturing plants to be developed more quickly and manual workflow to be optimized. They improve worker safety and reduce compensation costs resulting from accidents. Machines and other equipment can be positioned to optimize cycle time and avoid hazards. Manufacturing processes can be designed to eliminate inefficiencies and ensure optimal productivity. They can be used to: ensure that people can access the parts and equipment needed to assemble products; check that workers can effectively use any hand tools needed to perform manual tasks; and check that all tasks can be performed safely without requiring inordinate strength or exposing people to risk of injury.

Using digital humans enables designers to ensure that there is sufficient space to perform maintenance tasks, including space for hands, arms and tools, and space to install and remove parts. Designers can check that technicians can see what they are doing when they do specific maintenance tasks and that they can use the requisite hand tools. Digital humans enable people to be trained in multiple locations without the need for physical prototypes or actual equipment and so reduce the cost of training manufacturing and maintenance personnel.

There are many ways that digital humans can be developed and used to interact with products.

Using digital humans early in the design of a vehicle
for example, before a physical prototype is built:

- allows the design to be optimized for user comfort, visibility and access to controls
- ensures that people of different sizes will be able to see when they operate the vehicle
- ensures that the user population will be able to climb in and out of the vehicle easily
- ensures that the controls and foot pedals are within the reach of and can be operated by users
- ensures that the vehicle can be maintained
- ensures that the strength required to operate the vehicle is within the normal range.

Task:
Watch the video clip about ‘posture prediction’ and compare the process for testing the design without the use of digital humans.

Task:
Explain the advantages of using digital humans in product marketing

Task
Watch these two clips about Santos. Santos is a digital human model developed by the Virtual Soldier Research team in the University of Iowa’s College of Engineering; Santos is used to conduct human factors studies in design for numerous real-world applications including the military, manufacturing, sports and other domains.
Discuss how digital humans can improve design development.

- Digital humans can be used to represent joint resistance, discomfort, reach envelopes and visual fields.
- They can be used, for example, to measure the impact of clothing on human performance

**Motion Capture**

*Motion capture* is the recording of human and animal movement by any means, for example, by video, magnetic or electro-mechanical devices. A person wears a set of acoustic, inertial, LED, magnetic or reflective markers at each joint. Sensors track the position of the markers as the person moves to develop a digital representation of the motion.

Motion capture can reduce the cost of animation, which otherwise requires the animator to draw either each frame or key frames that are then interpolated. Motion capture saves time and creates more natural movements than manual animation, but is limited to motions that are anatomically possible. Some applications, for example, animated super-hero martial arts, might require additional impossible movements.

A motion capture session records the movements of the actor, not his or her visual appearance. The captured movements are mapped to a 3D model (for example, human or giant robot) created by a computer artist, to move the model in the same way. Capturing a number of users’ movements will allow designers to design better ergonomic products.

Motion capture allows the designer to understand the users’ physiological requirements.

The video link on the right demonstrates how motion capture is used to animate the character.

**Task**: Compare LED, magnetic or reflective markers to collect motion. Why might magnetic be better?
**Haptic technology**

Haptic technology is a technology that interfaces the user via a sense of touch. Haptic technology works by using mechanical actuators to apply forces to the user. By simulating the physics of the user’s virtual world, it is possible to compute these forces into real time.

**Task:** Watch the video and answer these questions

1. What are the two types of feedback?
2. How does Haptic technology work?
3. What everyday products feature Haptic technology?

New technologies in Haptic technology from the area of virtual reality (VR) now allow computer users to use their sense of touch to feel virtual objects. Touch is a very powerful sense but it has so far been neglected in computing.

Haptic technology allows the user to become part of a computer simulation and to interact with it, enabling the designer to observe the user’s performance and to design a better outcome. It can also be used in situations where it is difficult to train in the real environment. Haptic technology is also used in feedback devices used in home entertainment consoles.

State-of-the-art haptic (or force-feedback) devices allow users to feel and touch virtual objects with a high degree of realism. An artefact’s surface properties can be modelled so that someone using a haptic device could feel it as a solid, three-dimensional object with different textures, hardness or softness. Some commercial computer games already benefit from early haptic devices,
like the force-feedback steering wheels that torque and vibrate on bumpy driving-game roads. Scientists use computers to simulate not only the impact of a golf club hitting the ball, but also the springiness of a kidney under forceps.

There are so many potential opportunities for haptic technology:

- **Entertainment**: The possibilities are extremely exciting in the field of games and entertainment with haptic technology. The challenge will be bringing this technology down to a reasonable price point, along with an understandable, dynamic user interface.

- **Robots**: Haptic technology could greatly assist those with motor control issues or elderly people who have lost or degraded functions.

- **Wearable haptics**: With Google Glass and Kinect tweaks, it looks like we’re entering a whole era of wearable body sensors and computer networks. Devices like these could be tweaked to create a completely new paradigm of human and computer interaction, providing guidance for blind people, information and help for those with special needs, or even extra interaction while doing other tasks – cooking, driving, in a meeting, etc.

- **Touch screens**: Our touch screens right now offer vibrations and sound, but what about going beyond that to a touch screen experience that allows us to reach out and “feel” images on a screen, or a touch screen keyboard that makes it feel like we’re typing on actual, raised keys?

**Virtual reality**

Virtual reality is the ability to simulate a real situation on the screen and interact with it in a near-natural way. VR is computer generated and allows the user to interact with data that gives the appearance of a three-dimensional environment using a headset and other wearable technology.

Ford Motor Company uses VR to test and analyse the cabins of their vehicles. The VR units use haptic devices to provide a real sense of the space.

**Task** Click on the image on the right to watch a video clip.

VR provides valuable feedback from their engineers with regard to layout and mapping of controls. It provides feedback on the ergonomics of the interior and for the vision aspects of the car - what can be seen around and outside the car cabin.
Task: Explain how VR can be used by designers within the design process

Animation
Animation is the ability to link graphic screens together in such a way as to simulate motion or a process. Animation can be used to simulate various design contexts using digital humans to allow different scenarios to be tested.

Manufacturing companies can see how safe production will be when their products are being made through computer animations, without having to risk worker safety at any point.

Click on the image on the right to watch a video clip Modelling physical spaces- animated

Finite element analysis
Finite element analysis involves the calculation and simulation of unknown factors in products using CAD systems, for example, simulating stresses within a welded car part.

FEA consists of a computer model of a material or design that is stressed and analysed for specific data. FEA analyses stress, strain, or heat transfer in irregular shaped solid model designs. The three dimensional design is subdivided into small rectangles, called elements, on which standard stress formulas are applied.

Red usually represents an area of concern (i.e. higher heat or more stress). Orange through to yellow is low stress Blue = low stress Stress simulation through FEA
Fatigue analysis helps designers to predict the life of a material or structure. This analysis shows the areas where crack propagation is most likely to occur.

Heat Transfer analysis models the conductivity or thermal fluid dynamics of the material or structure. This can predict the surface temperature on a spaceship or the flow of plastic into a mould.

FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within it. This method of product design and testing is far more efficient compared to the manufacturing costs, which would accrue if each sample was actually built and tested.

FEA was carried out to understand why the World Trade Center collapsed the way it did.

**FEA Task:** Watch the video of a FEA of crashing a plane into a window. Why is this useful?

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**End of Topic 3.4 Tasks:**

**Compare** FEA with testing physical models

**Explain** how FEA can be used to show the maximum load of a vehicle and the stresses acting upon the vehicle

**Explain** how FEA can be used to show the forces acting upon an object while in use.

**Explain** how FEA can be used to allow the redesign areas of weakness discovered through FEA

**Compare** animation and virtual reality – Refer to different design contexts. Consider costs, client needs and development time.

**Discuss** the cost-effectiveness offered by animation and virtual reality.- Consider how this helps to reduce full-scale prototyping, which leads to a reduction in tooling costs, labour costs, energy and materials.

**Describe** haptic technology.

**Explain** how haptic technology and motion capture have enhanced design capability

**Discuss** the advantages and disadvantages of using software applications in different design contexts. – Consider product design, architecture and graphic design.