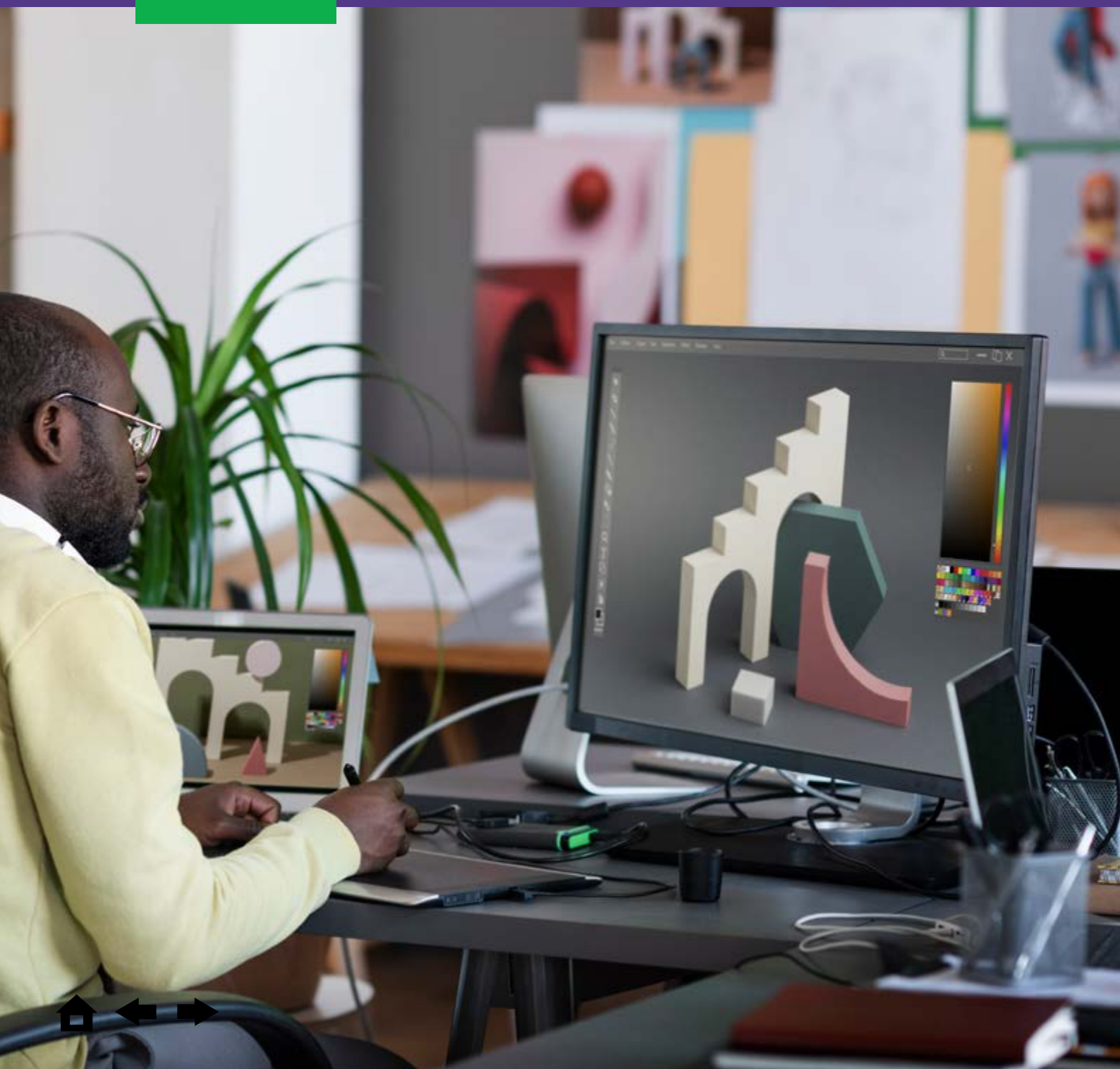
Manufacturing Engineering

Year 1

SECTION

4

RAPID PROTOTYPING



DESIGN AND PROTOTYPING

Rapid Prototyping

Introduction

In this section, we shall learn about rapid prototyping as a form of prototyping technique used for product development. You will also be introduced briefly to conventional prototyping techniques to give you a good basis to understand rapid prototyping. The principles behind rapid prototyping, the process, the advantages and disadvantages and its applications in product development will be thoroughly discussed. At the end of this section, you will be equipped with practical skills that will enable you to make prototypes of your design ideas. You will be exposed to hands-on activities to help you practice how to make prototypes using rapid prototyping techniques such as 3D printing

At the end of this section, you will be able to:

- Explain the fundamental difference between conventional prototyping and rapid prototyping
- Discuss the principles and processes of rapid prototyping.
- Explain the advantages and disadvantages of rapid prototyping
- Discuss the applications of rapid prototyping in manufacturing

Key Ideas

- **Prototypes** are smaller versions of actual designs that allow manufacturers to test the performance of their designs, correct design flaws and redesign before producing in full scale.
- **Conventional prototyping** refers to the process of creating physical models or prototypes using established, non-digital manufacturing techniques and tools such as machining, injection moulding, sheet metal fabrication, woodworking, handcrafting and many more.
- **Rapid prototype** involves the automated fabrication of intricate shapes from computer-aided design (CAD) data using a layer-by-layer principle

THE FUNDAMENTAL DIFFERENCE BETWEEN CONVENTIONAL PROTOTYPING AND RAPID PROTOTYPING

Prototyping is an essential part of the manufacturing process. Prototypes are smaller versions of actual designs that allow manufacturers to test the performance of their designs, correct design flaws and redesign before producing in full scale. Prototypes of products can be made using conventional or rapid prototyping techniques. This section discusses the major differences between conventional prototyping and rapid prototyping techniques.

Conventional Prototyping

Over the years, manufacturers have used conventional prototyping methods to create models of their designs for performance assessment. Conventional prototyping refers to the process of creating physical models or prototypes using established, non-digital manufacturing techniques and tools such as machining, injection moulding, sheet metal fabrication, woodworking, handcrafting and many more. These processes can be labour-intensive, time-consuming and expensive, prompting the need for easier, faster and cheaper prototyping techniques to enhance the work of manufacturers.

Rapid Prototyping

In recent years, rapid prototyping techniques have been proposed to enhance the manufacturing process. Rapid prototyping is a modern and innovative approach to creating prototypes and physical models quickly and cost-effectively using computer-aided design (CAD) software and additive manufacturing approaches. Examples of rapid prototyping techniques include but are not limited to fused deposition modelling, stereolithography, selective laser sintering, poljes technology, 3D printing and bioprinting.

Differences between Conventional Prototyping and Rapid Prototyping

Conventional prototyping and rapid prototyping are two distinct approaches to developing prototypes in the product design and development process. They differ in various aspects, including their processes, speed, cost and application. The key differences between conventional prototyping and rapid prototyping are presented in Table 4.1.

Table 4.1: Differences between conventional prototyping and rapid prototyping.

Item	Conventional Prototyping	Rapid Prototyping
Process and Technique	Uses traditional manufacturing methods such as machining, milling, or handcrafting. This process is time-consuming and may require skilled artisans or machinists to produce detailed models.	Involves creating prototypes layer by layer using computer-aided design (CAD) data. It relies on digital models and specialised machines to build physical prototypes quickly
Speed	Takes a considerable amount of time, especially for complex and intricate designs	Significantly faster
Cost	Can be costly, primarily due to labour, material and machine costs. Skilled machinists and artisans are often required, which adds to the expense.	Initial investment is relatively high. However, it can be cost-effective in the long run. It reduces labour costs, minimises material wastage, and enables quicker design iterations
Complexity	Better suited for certain types of materials and complex, large-scale prototypes. They are versatile but may have limitations in intricate and highly detailed designs	Well-suited for creating complex, intricate and detailed prototypes. It excels in producing prototypes with intricate geometries that would be challenging or impossible to create using traditional methods
Iterative designs	Due to the time and cost involved, conventional prototyping may limit the number of design iterations possible during the development process.	Facilitates iterative design, allowing designers to quickly modify and test multiple design variations. This accelerates the product development cycle
Materials	Offers a wide range of material choices, including metals, plastics and composites, depending on the machining or manufacturing process.	Material selection may be more limited compared to conventional methods. It primarily uses various types of plastics and resins

Activity 3.1

Making a prototype of a miniature shaft, nameplate or signage using available conventional prototyping and rapid prototyping techniques.

A: Conventional Prototype of a miniature nameplate

Conventional prototyping involves more manual and hands-on processes. Let us follow the steps below:

1. Design the nameplate manually with a detailed sketch considering the dimensions, font, and any other design elements.
2. Selection appropriate material for your prototype. .Basic materials such as wood, plastic, metal, or even cardboard can be used, depending on the purpose.
3. Cut the material to shape using basic tools like a saw, knife, or scissors, to the desired dimensions of the nameplate. Use files or sandpaper to remove all shape edges.
4. Apply the required design by either
   a. Engraving (hand-engrave the text and design using engraving tools).
   b. Hand Painting (paint the text and details by hand using fine brushes)
   c. Printing Print the text and design on a sticker and apply it to the nameplate.
4. Assemble components using glue, screws or rivets if the nameplate has multiple layers or pieces,
5. Give the prototype (nameplate) a finish by using sandpaper, polish, or paint the prototype to make it attractive and protect the surface.
6. Present your nameplate prototype for inspection and comments.

B: Rapid Prototype of a miniature nameplate.

For miniature nameplate using rapid prototyping follow the steps below:

1. Create a digital 3D model of the nameplate using CAD software like AutoCAD, Fusion 360, and ensure that the design is detailed, including text, logos, and other elements.
2. Scale the model down to the desired miniature size while maintaining the proportions and details.
3. Select appropriate prototyping method to print the miniature nameplate.
   a. Convert the 3D model into a format compatible with 3D printers, such as an STL file. (Remember to choose the appropriate material and print the miniature nameplate)
   b. Laser Cutting and Engraving: If you're using materials like acrylic or wood, prepare vector files for laser cutting. The machine will cut the shape and engrave the text or design onto the material.

4. Set up the 3D printer or laser cutter and the type of prototyping process. Calibrate it, and load the chosen material.
    a. For 3D printing, print the scaled model.
    b. For Laser cutting, cut and engrave the design on the material.
5. Review the prototype for accuracy and detail. For 3D-printed prototypes, clean up the model by removing supports, sanding, and possibly painting. For laser-cut prototypes, remove any burn marks, and assemble any parts if necessary.

Activity 3.2

In a group organised by your teacher discuss and make presentations on the major differences associated with the use of conventional and rapid prototyping techniques, with emphasis on the processes, complexities, production speed, time involved, needed skill sets, and cost implications.

Activity 3.3

Now, think about any product you may want to design to help your class or school and use rapid prototyping to design a prototype of it.

PRINCIPLES AND PROCESSES OF RAPID PROTOTYPING

This is one of the main ways we approach product development. Rapid prototyping is a technique that allows us to create physical prototypes quickly and efficiently, providing invaluable insights into the design and functionality of a product before it goes into full-scale production. However, to effectively utilise this technique, it's crucial to understand its underlying principles and processes.

The Principles of Rapid Prototyping

In rapid prototyping (RP), a solid object with a prescribed shape, dimension and finish can be directly produced from a CAD-based geometric model data stored in a computer without human intervention. The parts obtained by RP technology can be used directly as the prototype or as a mould for casting the prototype component. The principle of RP technology is based on speed, efficiency, and the layer-by-layer construction of physical models from digital designs.

The Process of Rapid Prototyping

The rapid prototyping process is described in Fig. 4.1, and can be summarised as below:

1. **Creation of the CAD model of the (part) design**: A component is modelled on a Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) system.
2. **Conversion of CAD model into Standard Tessellation Language (STL) Format:** The solid or surface model to be built is next converted into a format called the "STL" (Stereolithography) file format which originates from 3D systems. The STL file format approximates the surface of the model using polygons. Highly curved surfaces must employ many polygons, which means that STL files for curved parts can be very large.
3. **Slicing of STL file into thin sections**: A computer program analyses an STL file that defines the model to be fabricated and "slices" the model into cross sections.
4. **Building part layer by layer:** The software that operates RP systems generates laser-scanning paths or material deposition paths. Information computed here is used to deposit the part layer-by-layer on RP system platform. This step is different for different RP processes and depends on the basic deposition principle used in the rapid prototyping machine.
5. **Post-processing/finishing/joining**: At this stage, some manual operations are generally performed to give the model a good surface finish. The post-processing and surface finishing process can be done by sanding, polishing or painting. Also, excess elements adhered to the part or support structures are removed when cleaning the surface. A skilled operator is, therefore, required during the post-processing and surface finishing stage.

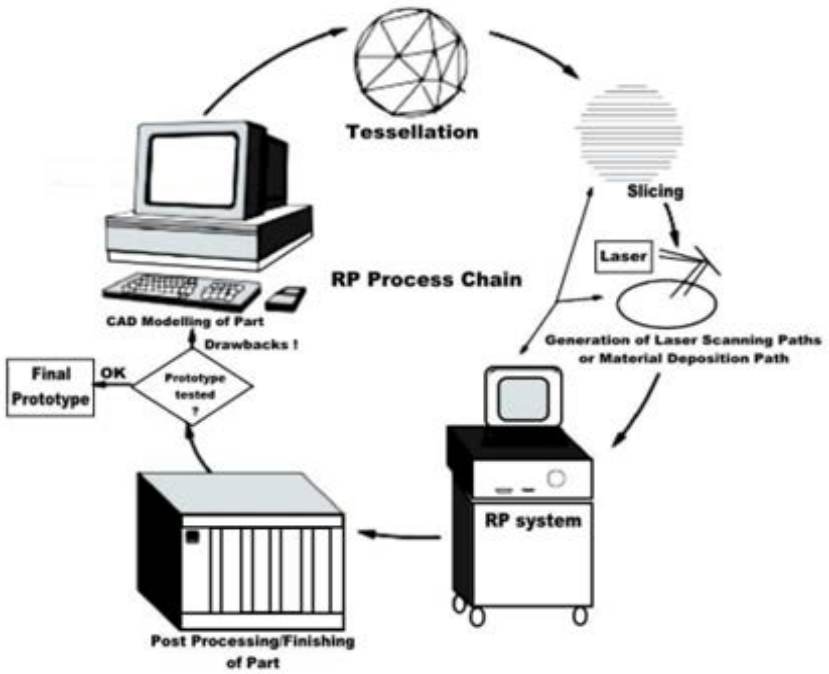


Fig. 4.1: The rapid prototyping process

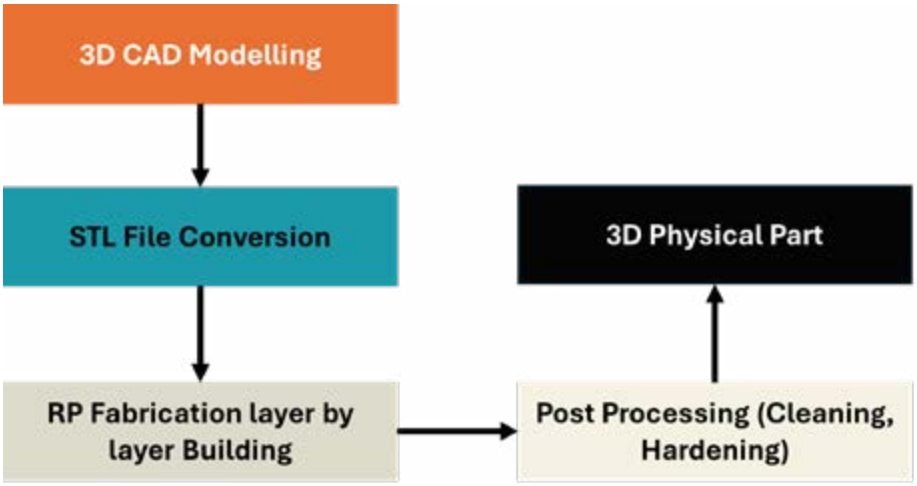


Fig. 4.2: Flow chart to produce a 3D model

Activity 3.4 : Exploring 3D Modelling

Visit a nearby 3D model printing studio to be introduced to the 3D modelling concept, for a hands on experience in creating your own 3D model

Write a summary of your experience at the 3D model printing studio in less than two pages under the following headings

1. Introduction
2. Tools, machines, or equipment and soft wares
3. Practical session
4. Printing process
5. Conclusion

Activity 3.4

Watch the video on the processes of developing a 3D model of a shock absorber of a car using a 3D printing process using the link below.

https://www.youtube.com/watch?v=qfmW6hdZupg

After the video, follow the steps below to design and make a 3D model of a shock absorber of a car.

1. Create a digital 3D model of the shock absorber of a car using Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) software like AutoCAD, Fusion 360, and ensure that the design is detailed, including text, logos, and other elements. Save your design in the Standard Tessellation Language (STL) format.
2. Scale the model down to the desired size while maintaining the proportions and details. Use slicing software to slice your 3D model into thin cross sections. This step prepares your model for the 3D printing process.
3. Set up the 3D printer and choose the appropriate material and print your prototype. Where you do not have a 3D printer, visit a nearby centre and print your prototype or watch videos, to understand how the printer builds the model layer by layer
4. Review the prototype for accuracy and detail. Clean up the model by removing supports, sanding, and possibly painting.

Activity 3.5

Prepare a presentation of the RP prototyping process, using the 3D printing process in Activity 2 as a case study.

ADVANTAGES AND DISADVANTAGES OF RAPID PROTOTYPING

Here we discuss the advantages and disadvantages of rapid prototyping. Innovation has become an integral part of the manufacturing process. Rapid prototyping provides a faster and cost-effective means of creatively making physical prototypes during product development. However, rapid prototyping has several disadvantages that need to be understood to help in making decisions when selecting a prototyping technique.

Advantages of Rapid Prototyping

Rapid prototyping has many advantages including:

1. **Faster Product Development:** Rapid prototyping significantly speeds up the product development process by allowing teams to iterate designs and concepts quickly.
2. **Reduced Costs:** Rapid prototyping allows designers to detect and address design flaws early in the development cycle. This helps to save substantial costs compared with making changes later in the process or after production has begun.
3. **Improved Communication:** Prototypes made using rapid prototyping techniques provide a tangible representation of the product. This makes it easier for stakeholders,

including clients, engineers and designers, to understand and discuss the design and functionality.

4. **User Feedback:** Rapid prototypes can be tested with end-users, providing valuable feedback that helps refine the design and align it with user needs and expectations.
5. **Elimination or Reduction of risk:** Rapid prototyping helps identify potential issues and risks early, enabling designers and manufacturers to address them before they become critical problems.
6. **Enhanced Creativity:** Rapid prototyping provides the freedom to quickly experiment with ideas. This can stimulate creativity and innovation among designers.
7. **Improvement in Iterations:** Rapid prototyping allows for multiple iterations, enabling continuous improvement until the final product meets the desired standards.
8. **Customisation:** Prototypes made with rapid prototyping techniques can be customised to focus on specific aspects of a product, allowing for the testing of individual features or components.

Disadvantages of Rapid Prototyping

Rapid prototyping has several disadvantages, including:

1. **Limited Functionality:** Prototypes may lack full functionality, which can lead to misconceptions about the final product's capabilities.
2. **2. Time and Resource Intensive:** Creating prototypes requires time and resources, and the rapid iteration process can be demanding for the team.
3. **Potential for Scope Creep:** Frequent changes during the prototyping phase can lead to scope creep, causing delays and increased costs.
4. **Quality Concerns:** Rapid prototyping may prioritise speed over quality, potentially leading to the development of unstable or inefficient solutions.
5. **Overemphasis on Aesthetics:** Prototypes can sometimes focus too much on visual design, neglecting underlying functionality and performance.
6. **Resistance to Change:** Teams or stakeholders may resist making significant changes based on prototype feedback, especially if they are attached to a particular design or concept.
7. **Risk of Misinterpretation:** Stakeholders may misinterpret the purpose of a prototype, thinking it represents the final product, which can lead to unrealistic expectations.
8. **Cost of Tools and Equipment:** Utilising advanced prototyping tools and equipment can be expensive, especially for small businesses or start-ups.
9. **Material Problems:** Most rapid prototyping techniques have a limited material range. Prototypes may also exhibit reduced material properties like surface finish and strength.
10. **Skilled labour:** Rapid prototyping requires skilled labour.

Activity 3.6

Making a diamond-nine arrangement of the advantages and disadvantages of rapid prototyping. To arrange cards of the advantages and disadvantages of rapid prototyping in a diamond-nine shape follow the steps given below.

1. Write down the advantages and disadvantages of rapid prototyping on separate cards
2. Arrange the cards in a diamond shape. Ensure that he most significant points should be at the top and bottom, and the least significant points should be towards the middle.
3. Start with the most significant advantage and disadvantage. Place these cards at the top and bottom of your diamond
4. Identify the next two most significant advantages or disadvantages. Place them on the second row of your diamond.
5. Adding more cards to each row as you move towards the middle of the diamond.
6. Start reducing the number of cards per row as you move towards the bottom of the diamond
7. Note that there is no right answer for this activity. It only encourages critical thinking and skills.

NB: Figure 4.3 represents a diamond-nine activity for the advantages of a rapid prototyping and figure 4.4 represents a diamond-nine activity for the disadvantages of a rapid prototyping

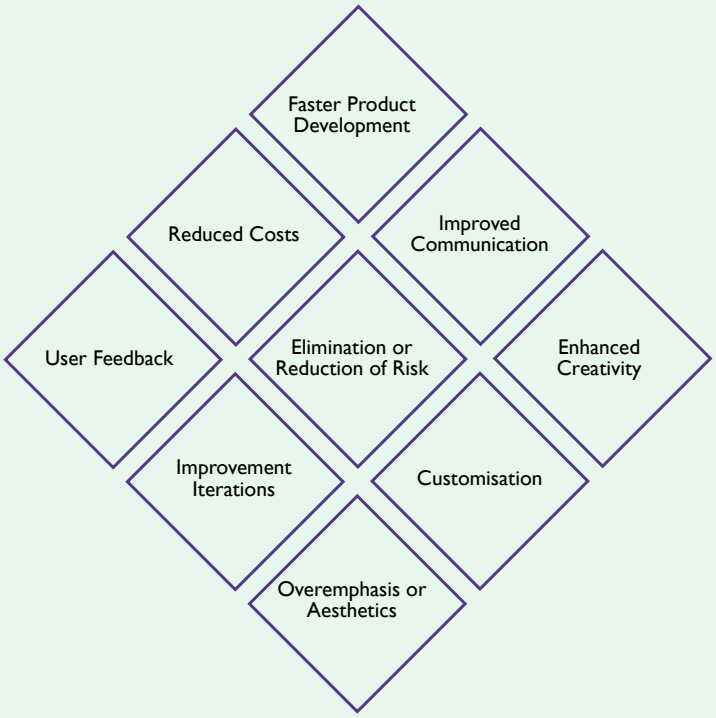


Fig. 4.3: Advantages of rapid prototyping on a diamond-nine

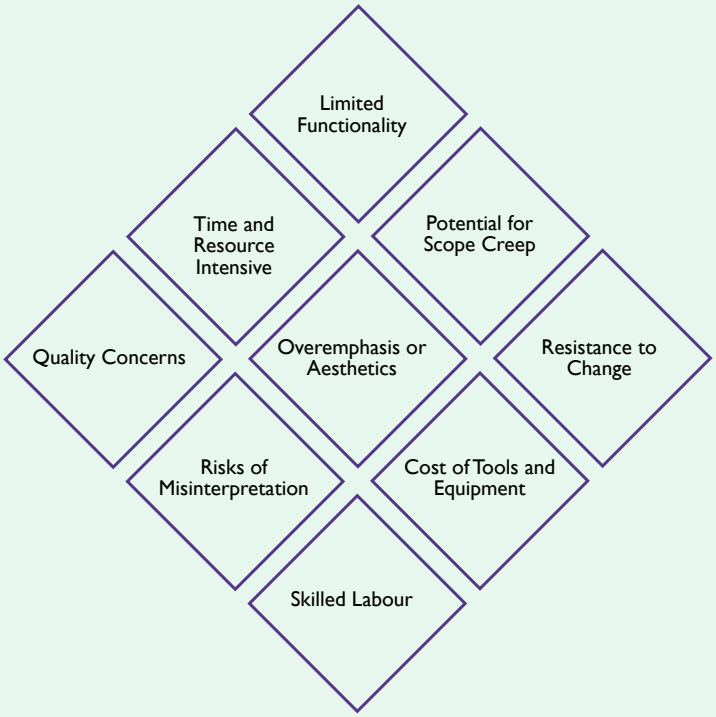


Fig. 4.4: Disadvantages of rapid prototyping on a diamond-nine

Now, make a diamond-nine activity on the advantages and disadvantages of rapid prototyping used in manufacturing on your own.

Activity 3.7

Make a search on the internet, read the book or watch the video on the advantages and disadvantages of rapid prototyping used in manufacturing using the link and the book below. https://www.youtube.com/playlist?list=PLQmc-I2-FO2Gnp2s74U5fBjfHDg1tUbOh

Gibson, I., Rosen, D.W., & Stucker, B. (2014). Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing (2nd ed.). Springer. Page 8

Steps:

1. Form research groups, in a mixed ability research groups, focus on either the advantages or disadvantages of rapid prototyping.
2. Discussion after completing your research, discuss your findings within your group. Make sure everyone understands the key points and address any questions or confusion.
3. Presentation Preparation: prepare a presentation to share your findings with the rest of the class. This could be a slide presentation, a poster, oral presentation or even a short video

4. Reflection: After all groups have presented, reflect as a class on what was learned. Discuss the strengths of each group's research and any new insights gained about rapid prototyping.

APPLICATIONS OF RAPID PROTOTYPING IN MANUFACTURING

Rapid prototyping helps validate the feasibility of a design and verifies that a design meets the desired requirements and specifications. It is essential in product development, customisation, concept modelling, production of end-use parts, reverse engineering and rapid manufacturing. Here we will discuss the application of rapid prototyping in product development.

Applications of Rapid Prototyping

Rapid prototyping has many applications, including;

1. Concept models and validation

Rapid prototyping allows for the development of physical concept models of future products. These concept models allow engineers and designers to test and validate their ideas. It also provides the opportunity for engineers and designers to explore the functionality of their initial concepts and demonstrate their validity to stakeholders for the approval of the development of the product.

2. Functional Prototyping

Engineers use rapid prototyping to produce prototypes of various designs. These prototypes, which are closely related to the final products, help engineers and designers accelerate their product development cycle through testing and evaluation.

This allows designers and engineers to refine their designs based on real-life performance data to ensure better product performance. For example, automobile manufacturing companies use rapid prototyping to create concept cars and test new designs and features before going into full production; components like engine parts, interior features and exterior panels can be rapidly prototyped to evaluate their performance and fit.

3. Customisation and Personalisation of Products

Rapid prototyping helps in the production of customised and personalised products specific to individual preferences and requirements.

This is extremely important in the medical, footwear and consumer goods industries where products need to be designed specifically for an individual. For instance, surgeons use rapid prototyping to create patient-specific implants for bone reconstruction, craniofacial surgeries, dental procedures, prosthetic limbs and other medical devices

that fit patients perfectly; shoe manufacturing companies can create prototypes of different sole designs to evaluate comfort, support and performance and also create footwear tailored to an individual's foot shape and preferences.

4. Tooling and Jigs

Rapid prototyping is used to create specialised tools, jigs and fixtures that aid in the manufacturing process. These tools can be produced quickly and cost-effectively, enhancing production efficiency.

5. Iterative Design

Rapid prototyping helps designers to easily iterate and refine their designs multiple times in a shorter span, leading to faster innovation and improvement of products.

6. Creation of Complex Geometries

Rapid prototyping allows for the creation of intricate and complex geometries that would be challenging or impossible to produce using traditional methods. This is particularly beneficial in industries like aerospace and medical devices.

7. Spare Parts Production

Maintenance and service industries such as the automotive and aerospace industries use rapid prototyping to quickly and efficiently produce spare parts for their maintenance and repair services.

8. Education and Training

Rapid prototyping is used in educational institutions and training programmes to teach students about product design, manufacturing processes and hands-on problem-solving.

Activity 3.8

Search the internet, read a book or watch the video on the application of rapid prototyping used in manufacturing using the link and the book below.

https://www.youtube.com/playlist?list=PLQmc-I2-FO2Gnp2s74U5fBjfHDg1tUbOh.

Follow the steps below for a group debate:

1. **Form Research Groups** In research groups, focus on the group representing an industry (such as the automobile, engineering, manufacturing, building, food and clothing industries
2. **Discussion** After completing your research in the application of rapid prototyping, discuss your findings within your group. Make sure everyone understands the key points and address any questions or confusion.
3. **Presentation Preparation** Prepare a presentation to share your findings with the rest of the class. Each group chooses their preferred mode of

presentation, such as oral presentation, webbings, mind maps, written reports, video presentations, or PowerPoint presentations.

4. **Presentation** Each group presents their findings to the rest of the class. This allows you and your peers to learn from each other and gain a broader understanding of the applications of rapid prototyping across different industries
5. **Reflection** After all groups have presented, reflect as a class on what was learned. Discuss the strengths of each group's research and any new insights gained about applications of rapid prototyping.

Activity 3.9

Your teacher will provide you with components used in varying industries such as the automobile, building, food, and clothing industries. (Car tyre, shock absorbers, trowel, wooden float, tea cup, serving tray)

1. **Form groups**: Form a mixed ability group of 4-5 classmates to work together on this task..
2. **Selection of components**: Your teacher will provide you with components used in various industries such as car tyres, shock absorbers, trowels, wooden floats, tea cups, serving trays, bottles, etc. Your group should select a component from the given components.
3. **Design of Prototype:** You are tasked to design a prototype of your choice based on your selected component. The applications of rapid prototyping in your design process should be considered.
4. **Creation of Prototype** In your group cooperate to create your prototype using 3D printing. Document the process used and any challenges encountered during the prototyping creation processes.
5. **Testing and Evaluation:** Test your created prototype for its functionality and evaluate its performance. Record your observations and findings.
6. **Presentation Preparation:** After testing and evaluation, prepare a presentation on your prototype. The presentation should
7. **Presentation**: Then present your prototype and your findings to the rest of the class, this should include the design process, the challenges faced, how you overcame them, and your observations and findings from the testing and evaluation process. This allows you to learn from each other and gain a broader understanding of the applications of rapid prototyping across different industries
8. **Reflection** After all groups have presented, reflect as a class on what was learned. Discuss the strengths of each group's project and any new insights gained about applications of rapid prototyping.

Now, think about any product you may want to design to help your class or community and use rapid prototyping to design and construct.

Review Questions

1. What is the major difference between rapid prototyping and conventional prototyping?
2. How does the use of conventional or rapid prototyping techniques affect the duration of the development of a product?
3. How do the technologies used in conventional prototyping differ from those used in rapid prototyping?
4. What are the steps involved in the rapid prototyping process?
5. What is the justification for slicing the STL file into thin layers for the design of the models?
6. As a manufacturing engineer in your company, outline any three reasons why rapid prototyping should be adopted in all the production sections of the company.
7. Discuss any three reasons why rapid prototyping must not be over-encouraged in industries.
8. Evaluate the economic impact of rapid prototyping on the local manufacturing industry.
9. Discuss the benefits the local automotive and manufacturing industries can derive from using rapid prototyping.

Extended reading

1. Gibson, I., Rosen, D.W., & Stucker, B. (2014). Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing (2nd ed.). Springer.
2. Simpson, T.W., Yu, J., & Jiao, J. (2020). Design for Additive Manufacturing: Guidelines and Applications for Industrial 3D Printing. CRC Press.
3. Chua, C. K., Leong, K. F., & Lim, C. S. (2010). Rapid Prototyping: Principles and Applications (2nd Edition). World Scientific Publishing
4. Gibson, I., Rosen, D.W., & Stucker, B. (2014). Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing (2nd edition.). Springer. (Page 8)

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