United Nations | Department of Economic and Social Affairs

UNDRR
UN Office for Disaster Risk Reduction

Risk-informed Governance and Innovative Technology for Disaster Risk Reduction and Resilience

Module 2.2: Changing How We Make and Acquire Things

Contents

1. Additive Manufacturing

1. Innovative Materials

Learning Outcomes

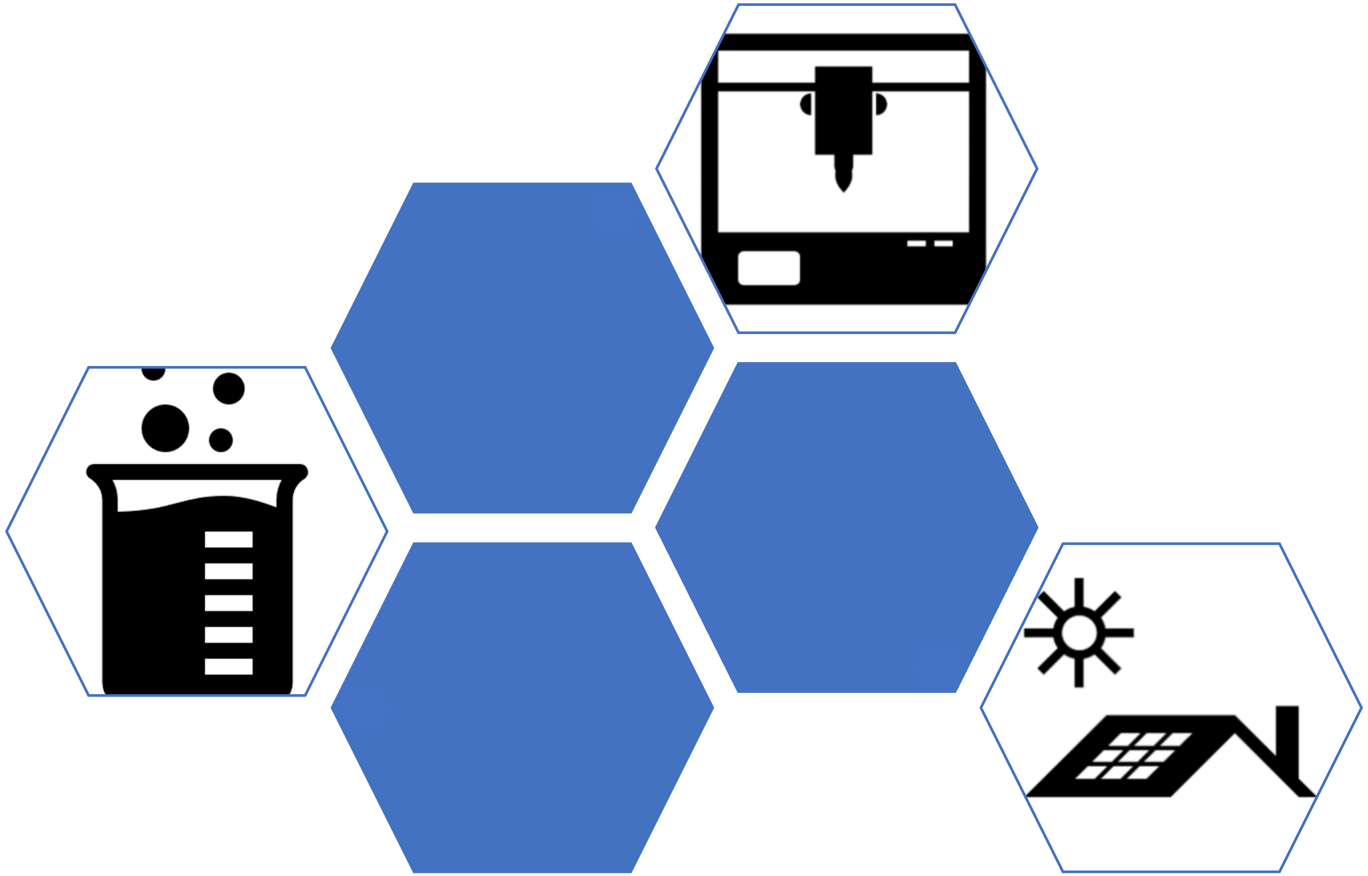
At the conclusion of this Session, Participants will be able to:

- Identify where access to Additive (3-D) Printing technology will support disaster preparedness, disaster response, or disaster recovery efforts.

- Promote or apply the use of new construction materials and methods in a manner that is situation-appropriate and that balances the cost of such methods and materials with the benefits that may be gained.

Introduction

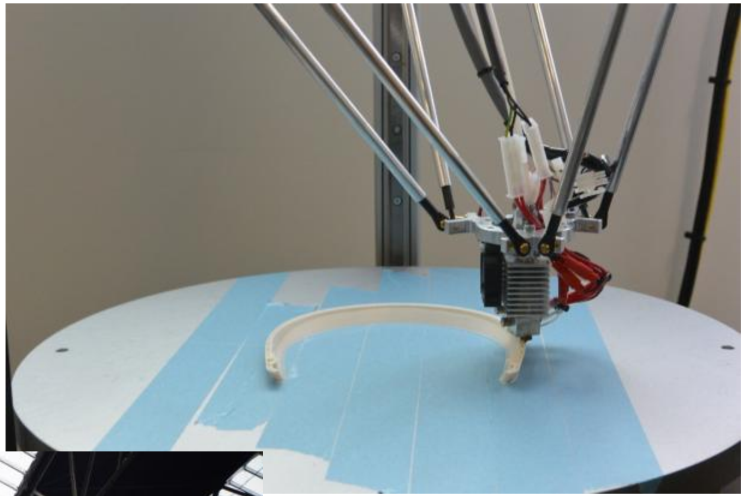
- **Additive Manufacturing**
- **Innovative Materials**



1. Additive Manufacturing

▪ Additive Manufacturing

- Has existed for about 30 years
- Offers several benefits to the DRM context
- Advancement/Improvement in:
  - Size / portability
  - Raw materials
  - Design simplicity
  - Product operation
  - Cost



Top image: 3D printer creating a plastic object. Credit: Malavoda, 2014.

Left image: The MX3D bridge project resulted in the first fully-3D printed stainless steel bridge. The fully functional pedestrian bridge built for the city center of Amsterdam serves as proof of concept that 3D printers can construct community infrastructure.
Credit: Ars Electronica, May 30, 2018.

1. Additive Manufacturing

▪ Traditional Manufacturing Methods

- Machining
- Injection Moulding
- Casting
- Forming
- Joining

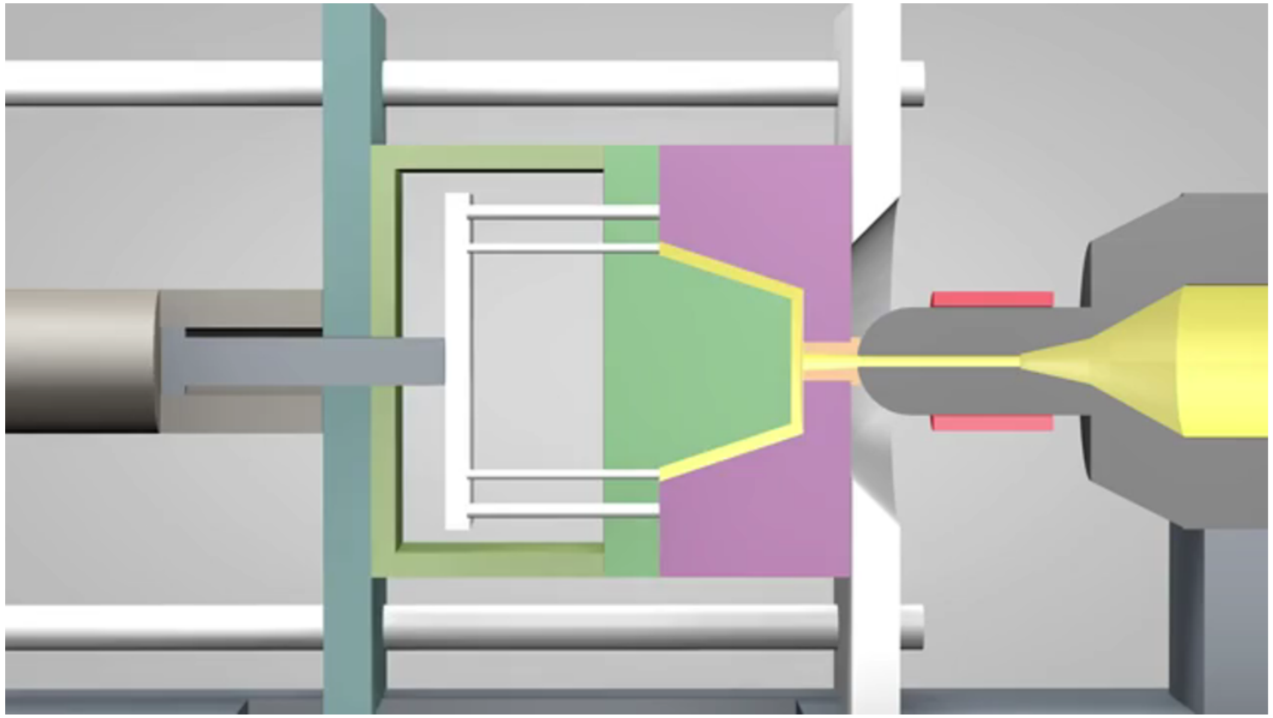
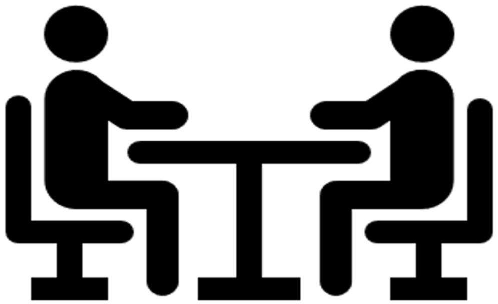


Image: The injection moulding process.
Image credit: Bill Hammack, 2015.

Group Work and Activities



Group Work and Activities

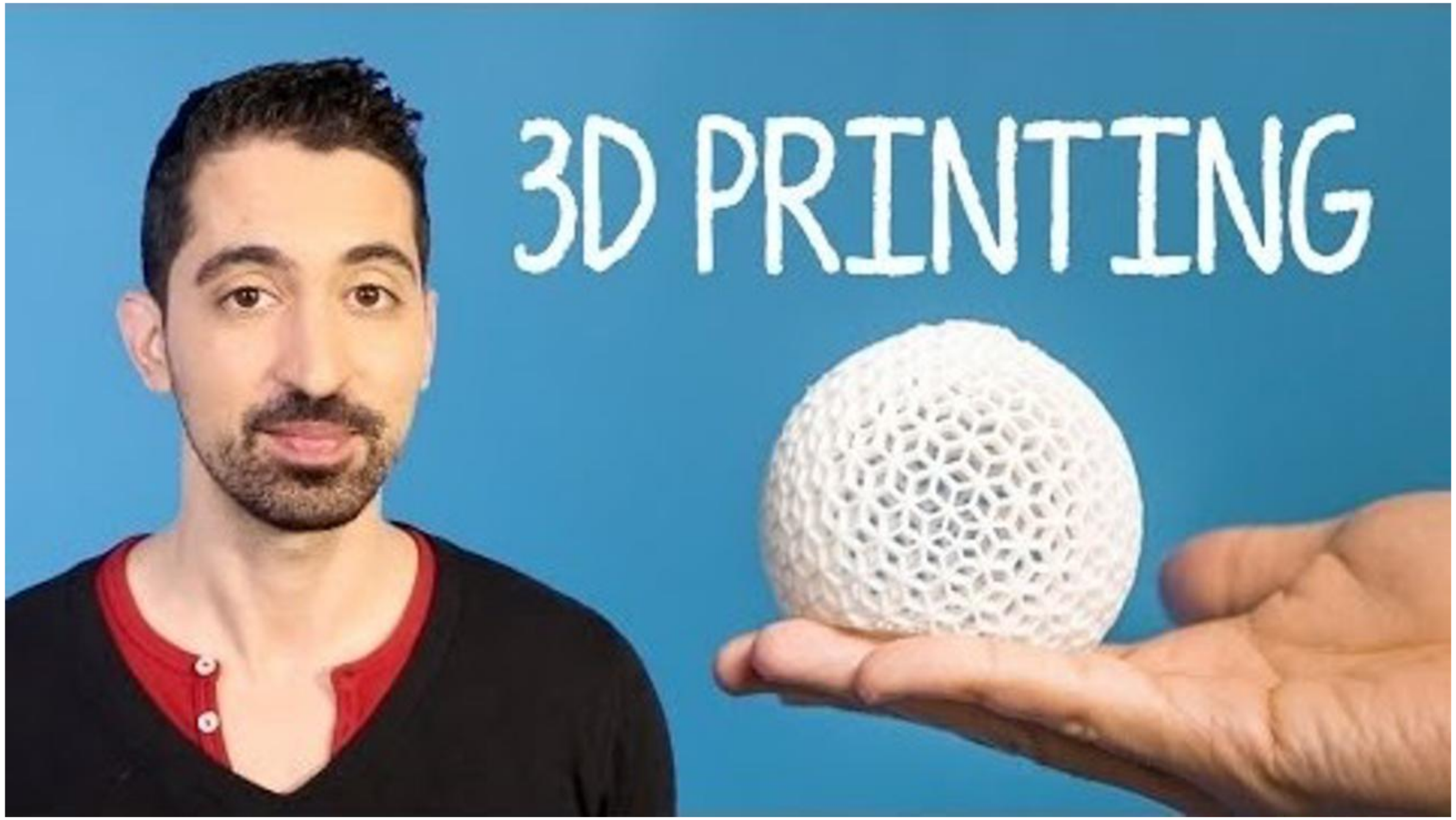
▪ Discussion 1: Use of Manufactured Goods in the Disaster Context

- For each of the disaster management phases (Mitigation and Preventions, Preparedness, Response, and Recovery), identify one product that typifies that function. Identify the manufacturing process that is used to created it. Identify any challenges that might exist with respect to procurement of that product using these traditional methods.

- For example: Child-sized surgical tools are often unavailable in disaster clinics. These are produced through a variety of manufacturing methods, including machining, injection moulding, joining, and forming. In the early days of disasters, it can be difficult to transport these needed implements into the disaster area if transportation routes are blocked, or if communications systems are nonfunctional.

1. Additive Manufacturing

▪ Additive Manufacturing Explained



Video: What is 3D Printing and How Does It Work?
Image credit: Mashable, 2014.

1. Additive Manufacturing

▪ Additive Manufacturing Types

- Fused Filament Fabrication (FFF)
- Laser Sintering
- Stereolithography
- Material Jetting and Binder Jetting
- Directed Energy Deposition

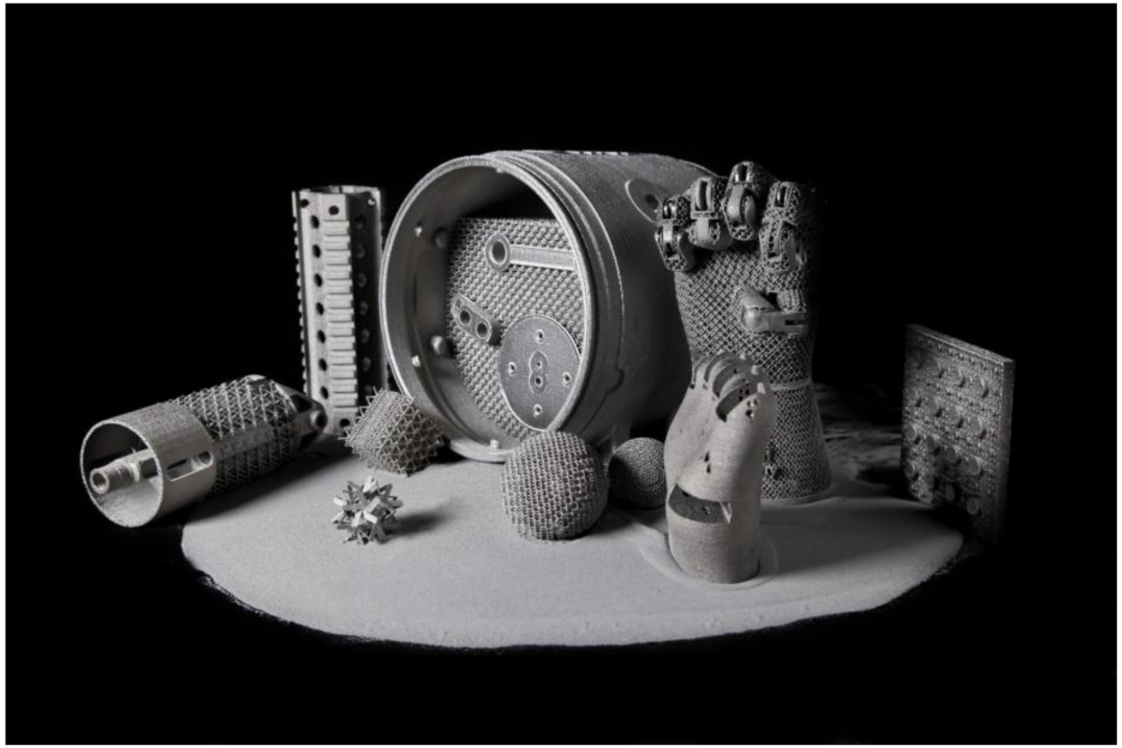


Image: Products of additive manufacturing processes.
Image credit: Oak Ridge National Laboratory, 2011.

1. Additive Manufacturing

▪ Fused Filament Fabrication (FFF)

- Traditional commercial ‘3D Printer’ technology
- A continuous filament of thermoplastic is fed through a heated printer head
- Raw material changes shape when heated but holds shape when cooled
- Printer head driven by a computer processor as instructed by a design file
- Printer head most often moved in two dimensions
- Filament winding uses a rotational depositional model

Video: Fused Deposition Modeling (FDM) Explained.
Image credit: Solid Concepts, 2013.

1. Additive Manufacturing

▪ Laser Sintering and Melting

- Sintering = compacting and forming a solid mass by applying heat or pressure without melting
- Types of laser additive manufacturing:
  - Selective laser sintering (SLS)
  - Selective laser melting (SLM)
  - Electron-beam manufacturing (EBM)
  - Direct metal laser melting (DMLM)
  - Laser powder bed fusion (LPBF)
  - Laser powder forming

- High power-density laser melts and fuses metallic powders in successive layers
- Typically produces better results than filament fabrication.
- Machines often more expensive

Video: How It Works: Direct Metal Laser Sintering.
Image credit: Solid Concepts, 2013.

1. Additive Manufacturing

▪ Stereolithography

- 3D printer that uses a liquid polymer rather than a powder or solid raw material
- A beam of ultraviolet light is focused from above or below onto the print bed
- Layers of liquid polymer are added successively
- This technology is rapidly coming down in price with advancement, from $250,000 for a machine just a few years ago to just a few thousand dollars today.

Video: How It Works: Stereolithography.
Image credit: Solid Concepts, 2013.

1. Additive Manufacturing

▪ Material Jetting (MJ) and Binder Jetting (BJ)

- Similar to filament-based machines, but use a liquid photopolymer
- Similar to an inkjet printer
- Also similar to stereolithography
- Raw material (photopolymer) sprayed in a pattern and hardened using ultraviolet light
- Higher speed / multiple colors / smooth surfaces
- High price / lower relative strength
- Binder jetting systems spray the binder onto the raw material, which is in powder form

Image: Multi-color item produced using material jetting
Image source: 3D Hubs, 2019.

1. Additive Manufacturing

▪ Directed Energy Deposition (DED)

- Combines several of the other additive technologies already mentioned
  - Powder sintering system
  - Jetting systems
  - Filament systems
- Have a moving print head that deposits the material in the configuration defined in the 3D model
- High-energy laser, electron beam, or plasma arc melts the raw material which binds to the underlying layer

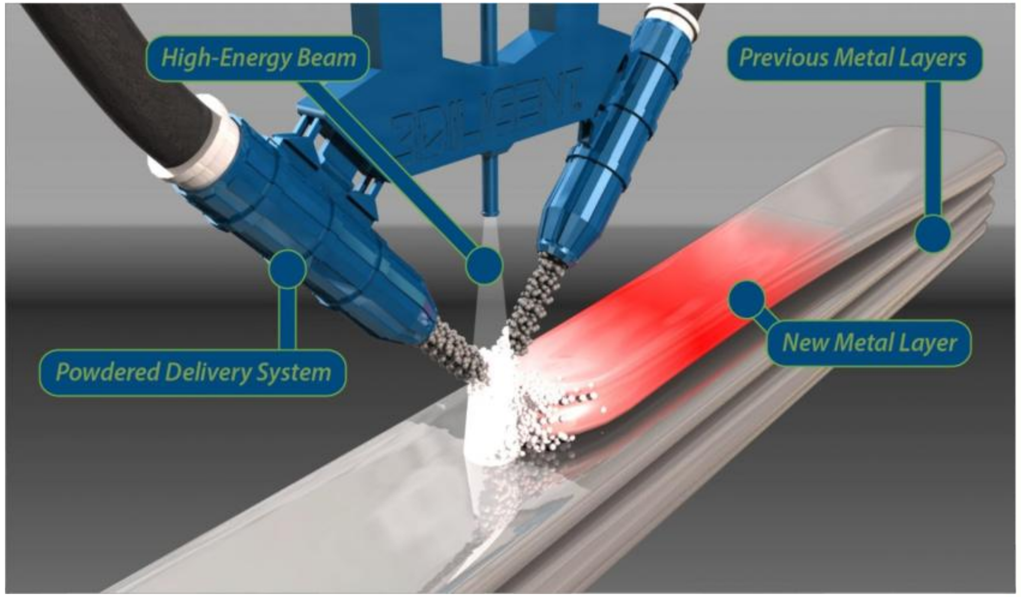


Image: Directed Energy Deposition.
Image credit: 3Diligent, 2019.

1. Additive Manufacturing

▪ Basic Parts of an Additive Manufacturing System

1. Input Material
2. Print Head
3. Build Plate
4. Axes
5. 3D Design File

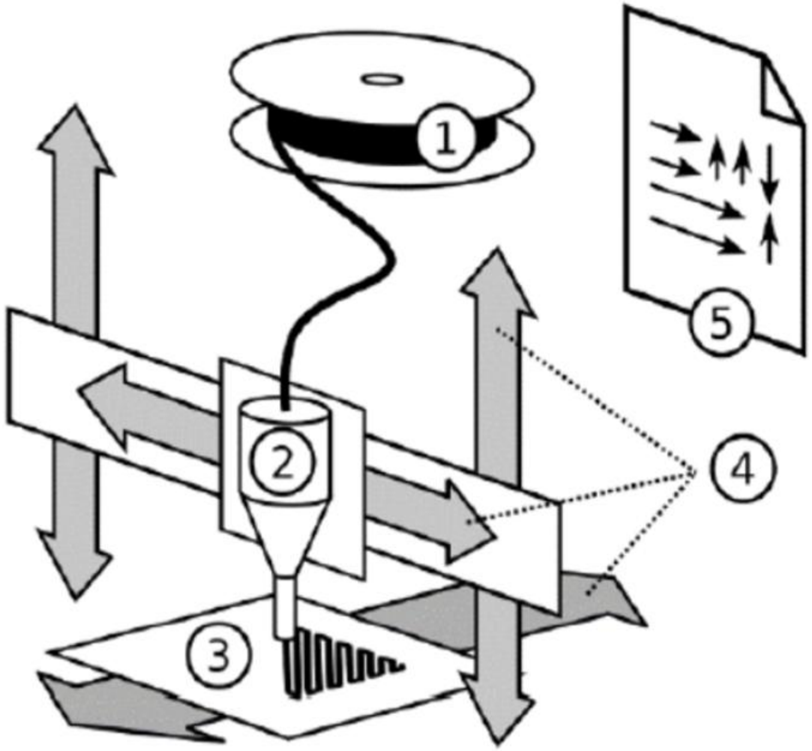


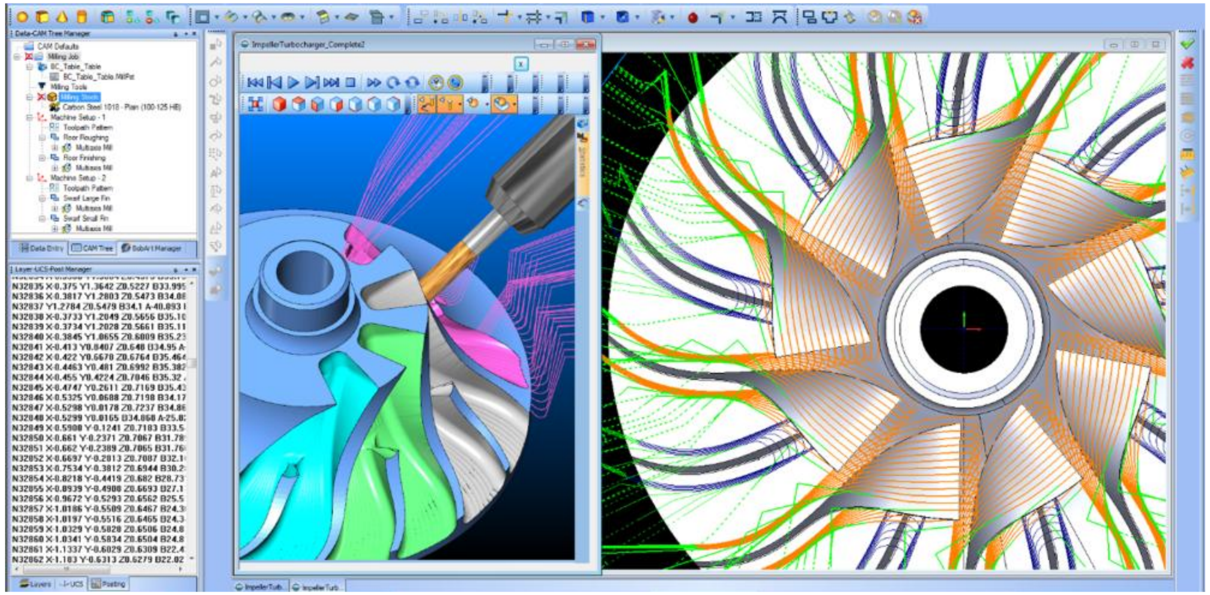
Image: Common Parts of 3D Printers.
Image credit: Sargent and Schwartz, 2019.

1. Additive Manufacturing

- **3D Design File**

1. 3D Scanner

2. Computer-Aided Design (CAD)

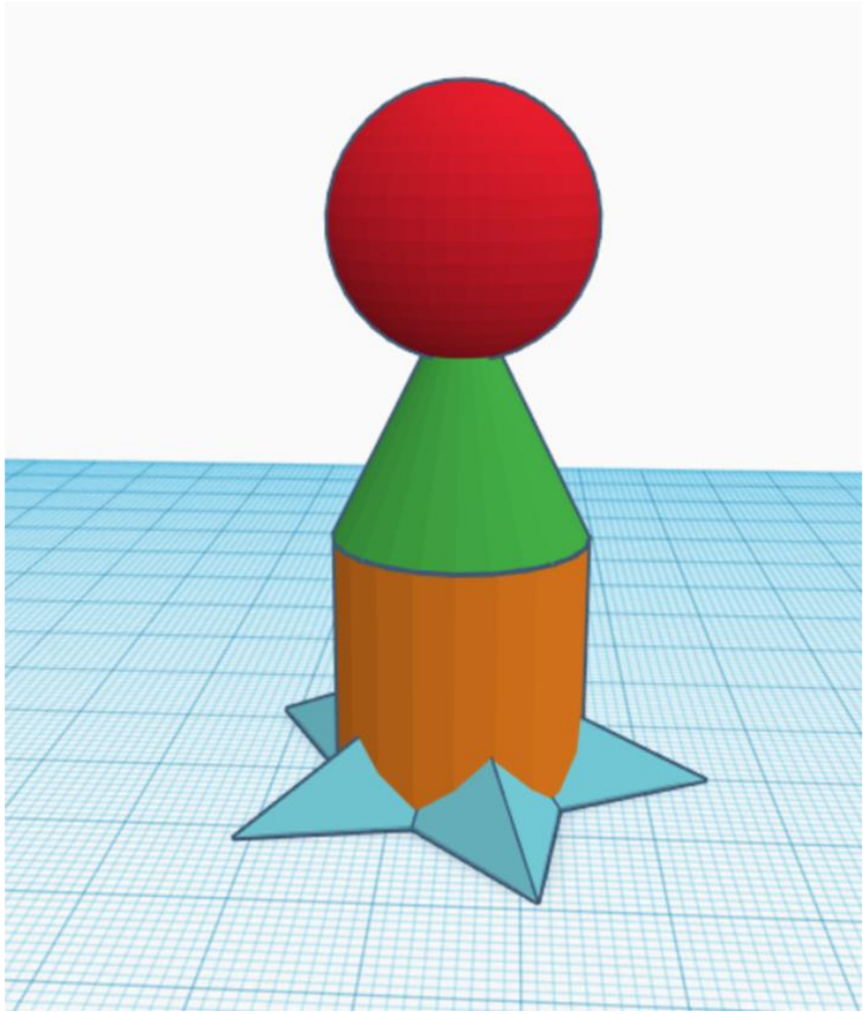


Top: Handheld 3D Scanner (source: 3D-Scanned Studio, 2011.)
Bottom: CAD screenshot. Source: BobCAD-CAM, 2019.)

1. Additive Manufacturing

▪ Activity: Simple CAD Drawing

1. Groups of 2-3 Students
2. Open www.tinkercad.com
3. Select “Join Now”
4. Create a Personal Account
5. Once logged in, select “Create New Design”
6. You have 15 minutes to recreate the 3D figure displayed



1. Additive Manufacturing

▪ Advantages and Disadvantages

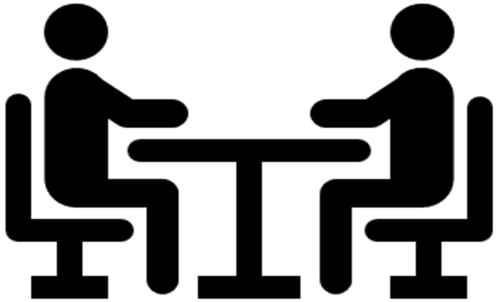
Advantages

- Lower unit cost than some other methods
- Cost effectiveness of small print runs
- Complex inner support structures possible
- Ease of design modification
- Mass customization
- No need for large inventories
- Decentralized manufacturing
- Transportability
- Very little skill required
- Very few design constraints

Disadvantages

- Energy requirements
- Tendency to be slow
- Cost may be higher for large production runs
- Larger items cannot be easily or economically printed
- Post-production finishing often required

Group Work and Activities



Group Work and Activities

- **Discussion 2: Country-Specific Advantages and Disadvantages**

- **The Facilitator** can lead a discussion about advantages and disadvantages that may apply in unique geographic or political contexts. For instance, there may be environmental concerns associated with the use of plastics in many additive manufacturing situations. There are also concerns about what might be printed with the devices, such as weapons.

Supply Chain Challenges

- Supplies do not exist in the impacted region
- Supplies do not exist in the country
- Supplies exist in the impacted region, but they are not appropriate for needs
- Supplies exist in the country, but it is not possible to transport them to the impacted area due to distance or transportation infrastructure damages/constraints
- Supplies exist, but so few of the specialized items are needed that the unit cost of procuring is prohibitively high
- Conflict prevents the safe delivery of goods
- Damage at inventory storage sites
- Age of inventoried items (leading to a loss of utility)
- Theft of supplies
- Delays related to customs or import requirements

1. Additive Manufacturing

- **Standard Humanitarian Supply Chain**

Source: James, 2008.)

1. Additive Manufacturing

- **3D Printing by Sector**

3D Printing Items by Sector (FieldReady.org)

Sector/ Cluster	Printed Items
WASH	Pipe/hose connectors, spigots, washing points, soap holders and dispensers, latrine hinge-covers
Health	Medical disposables (e.g. IV bag hooks, oxygen splitters, umbilical cord clamps), combs, medical waste containers, prosthetic limbs, 3D models for planning and patient education
Camp Management	Durable signs, clipboards and items to secure rope for crowd control
Shelter	Tent stakes, enclosures, tools and rope clamps
Food/Nutrition	Measuring cups, specialty utensils and eating ware
Protection	Pill dispensers, eye-glass repair, family images/figurines, toys, rudimentary locks, whistles, door jams
Education	Learning tools and models, musical instruments
Logistics	Spare parts (plastic and rubber), office organizers, tablet stands, keyboard key replacements
Telecommunications	Connectors, wire wraps, zip ties, equipment holders and organizers
Early Recovery	Plastic voucher cards, items for home-based employment, agriculture, and sustainable livelihoods

Source: FieldReady.org, 2019.)

1. Additive Manufacturing

▪ Case Study: Field Ready Parts Catalog

- **Problem**: In disasters, there is a sudden increase in need for manufactured items
- **Need**: Rapid access to various items
- **Obstacle**: Humanitarian actors do not always know what items are suitable for 3D printing, or may not have data files to print them from
- **Solution**: Catalog of items that can be produced with 3D printing, including information on difficulty, risks, and downloadable data file

Image: Screen shot from Field Ready Parts Catalog showing the plans for a bottle cap that can be used to safely dispose of hypodermic needles.
Source: Field Ready, 2019.

1. Additive Manufacturing

▪ Case Study: Portable Industrial Sized 3D Printer

- **Problem**: In disasters, there is a sudden increase in need for manufactured items
- **Need**: Rapid access to various items
- **Obstacle**: Many 3D printers cannot print objects larger than their housing, so possibilities are limited by size; at the same time, shipping of larger systems is difficult
- **Solution**: House a 3D printer in a readily transported shipping container

Video: Millebot operation time-lapse video.
Source: Millebot, 2019.

1. Additive Manufacturing

▪ Case Study: Using Recycled Plastic to Manufacture

- **Problem**: In disasters, there is a sudden increase in need for manufactured items
- **Need**: Rapid access to various items
- **Obstacle**: 3D printers require a power source and raw materials, both of which may be in short supply following a disaster
- **Solution**: Solar-powered 3D printer which uses waste plastic as a raw material

Image: Deakin University team working in Solomon Islands following a 2018 cyclone printing parts to repair water infrastructure.
Source: lulzbot.com, 2019.

1. Additive Manufacturing

▪ Case Study: Infrastructure Repairs in Nepal

- **Problem**: Disasters cause significant impacts to critical infrastructure, including nodes and networks
- **Need**: Rare and custom parts
- **Obstacle**: Parts are not readily-available due to cost, lack of inventory, or transportation challenges
- **Solution**: Custom printing of parts to facilitate the rapid resumption of critical infrastructure services

Top Image: Staff from Field Ready use a 3D printer to create a custom pipe fitting in Nepal following the 2015 earthquake. Bottom Image: Blue custom fitting produced using a 3D printer. Image source: Jones, Sam. 2015. When Disasters Strike, It's Time to Fly In the 3D Printers. The Guardian. December 30.

1. Additive Manufacturing

- **Video: 3D Printed Home**

Video: On-site 3D printed home

1. Additive Manufacturing

▪ Case Study: 3D Printed Resilient Homes

- **Problem**: Impacts to housing caused by disasters can have profound negative affects to occupants
- **Need**: Disaster resilient housing
- **Obstacle**: Disaster resilient design and materials are generally more expensive, and the requisite knowledge to construct such structures may not exist locally
- **Solution**: 3D-printed houses using high-strength materials and design

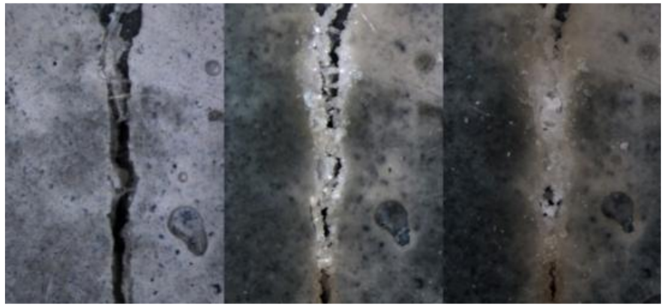
Image: 3D Printed Home
Source: Web Urbanist, 2019.

2. Innovative Materials

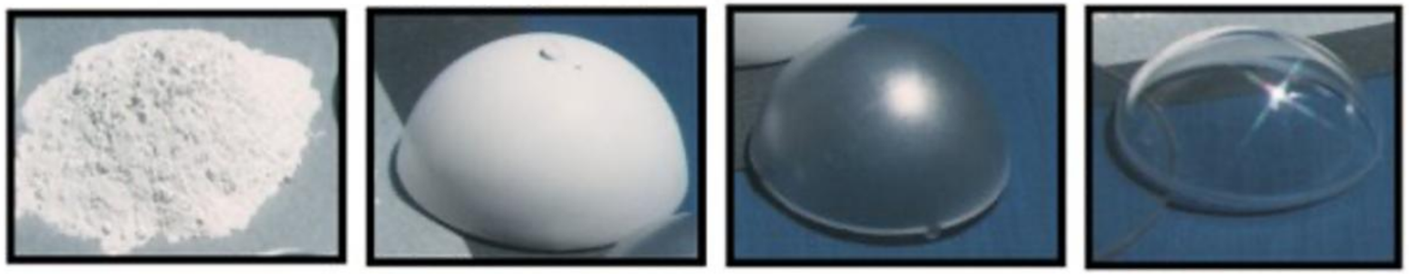
▪ Innovative Materials

1. Existing materials used in an innovative way

2. Existing materials modified to achieve new properties or functions



3. Entirely new materials



Top Images: Image: permeable pavers; Middle Image: self-healing concrete; Bottom Images: Aluminium Oxcynitride in various stages of production

2. Innovative Materials

- ## Incremental Materials Innovation

World Economic Forum. 2016. Shaping the Future of Construction: A Breakthrough in Mindset and Technology. Reference 220416. http://bit.ly/32ZLHAs.

2. Innovative Materials

▪ Case Study: Nairobi Airport Removable Flood Barriers

- **Problem**: Homes, buildings, and other facilities are facing increased flood risk due to climate change and other factors
- **Need**: Flood mitigation retrofits
- **Obstacle**: Retrofitting buildings can be difficult, expensive, aesthetically unpleasing, and only marginally effective
- **Solution**: Removable lightweight aluminum flood panels

Image: Removable floodwall installed at the Nairobi Airport in Kenya
Source: Flood Control International, 2019.

2. Innovative Materials

▪ Case Study: Thin Shell Rooftop

- **Problem**: Electrical demand of cities is contributing to climate change
- **Need**: Construction design that incorporates renewable energy systems
- **Obstacle**: Current construction styles and techniques do not always lend themselves well to renewable energy innovations
- **Solution**: Thin mesh-mounted roof that incorporates solar power generation and harnessing of photothermal energy.S

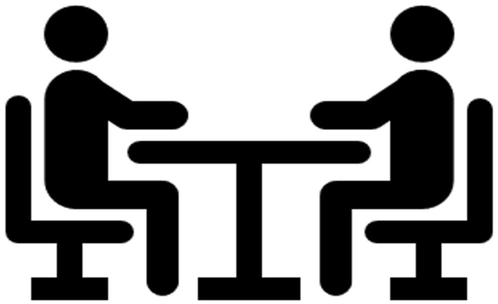
Image: Thin Shell Roof being prepared for installation on an apartment building
Source: Staughton, 2018.

▪ Case Study: Semi-Permanent Shelters

- **Problem**: Disasters often destroy homes; disaster operations have significant facility requirements
- **Need**: Durable, quickly-constructed buildings
- **Obstacle**: Buildings tend to be quickly constructed or durable, but not both
- **Solution**: Shelter made from durable and easy-to-install Concrete Canvas®

Image: Concrete Canvas® shelter in various stages of installation
Source: Flood Control International, 2019.

Group Work and Activities



Group Work and Activities

▪ Discussion 3: Use of Semi-Permanent Quick-Setup Shelters

- Each country is unique in terms of its capacity and its needs, which are partly driven by hazard exposure. These factors all help to determine the utility of different innovative technologies, including the Concrete Canvas® shelter.

- Participants should work in groups to identify specific disaster-related needs for which such a shelter would provide the ideal solutions. Participants should communicate what is currently being used to meet this need, and why this innovation would improve capacity.

2. Innovative Materials

▪ Case Study: Self-healing Concrete

- **Problem**: Cracks in concrete quickly degrade the structures and reduce disaster resilience
- **Need**: cracks need to be quickly repaired or they will grow and further compromise the structure
- **Obstacle**: Regular building maintenance is difficult, expensive, and can only occur if cracks are known
- **Solution**: Concrete that heals itself automatically using bacteria and a growth agent

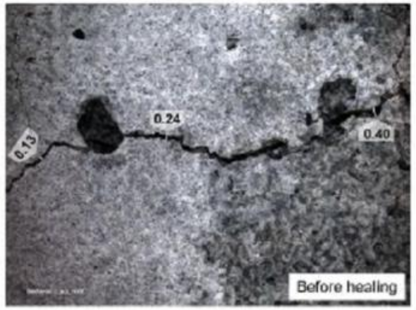


Image: Example of self-healed concrete
Source: Sanju Bhandari, 2015.

2. Innovative Materials

▪ Case Study: Lightweight Seismic Reinforcement

- **Problem**: Many buildings are inadequately equipped to manage seismic risk
- **Need**: Seismic reinforcement
- **Obstacle**: Many seismic reinforcement options are either too expensive, too difficult to work with, or not aesthetically pleasing
- **Solution**: Synthetic materials made of carbon fiber and other materials provide greater strength and less weight than traditional materials and are considered aesthetically pleasing.

Image: Komatsu Seiten Building with Strand Rod support structure
Source: Komatsu Seiten, 2019.

2. Innovative Materials

▪ Case Study: Rain Absorbing Roof Mats

- **Problem**: Cities retain heat, creating heat islands that have many associated problems
- **Need**: Construction techniques that help to reduce urban heat retention
- **Obstacle**: New construction methods that cause a significant increase in cost or weight are not appealing to the construction sector
- **Solution**: Ultra-thin mats that absorb water and pull heat from buildings by becoming hydrophobic at high temperatures

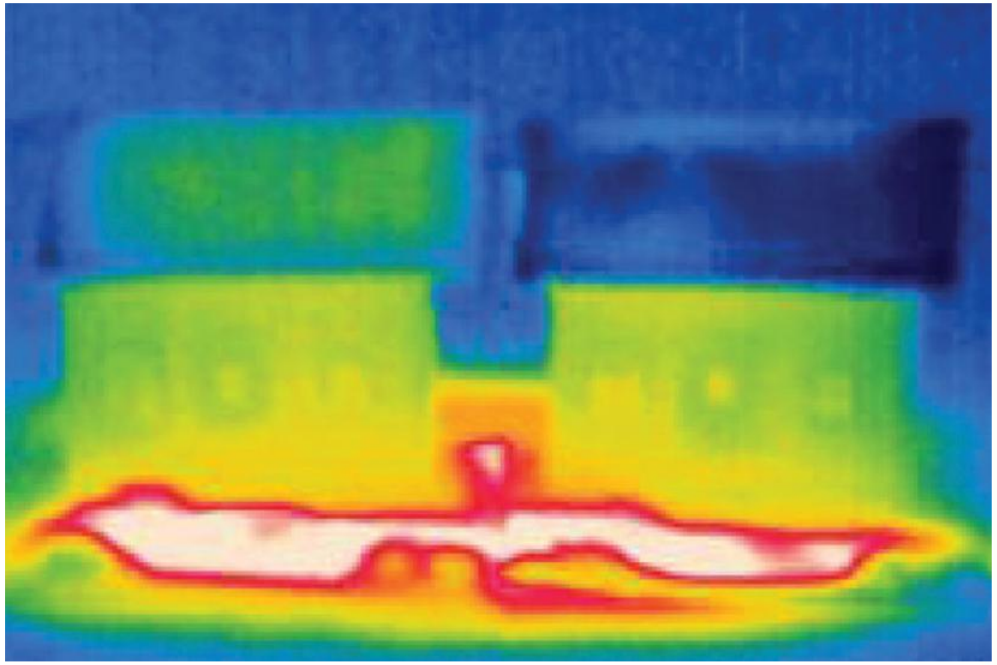


Image: Thermal sensing of two model houses; the house on the right has a rain-absorbing roof mat installed.
Source: Adam Williams, 2012.

Group Work and Activities

Group Work and Activities

▪ Discussion 4: Promoting Research and Development of New Materials

- Development of new construction materials and methods is an important part of the science and technology agenda. Countries tend to focus research support on solutions that meet their own problems.

- Participants can discuss how, within their own countries, new materials development is being promoted, and what is being done to promote public private partnerships for innovative materials development.

Background Materials

Key Readings	• OCHA. 2015. Shrinking the Supply Chain: Hyperlocal Manufacturing and 3D Printing in Humanitarian Response. http://bit.ly/2Y9cJUI. • Kuckelhaus, Markus. 2016. 3D Printing and the Future of Supply Chains. DHL Trend Research. http://bit.ly/2PgrGAb. • World Economic Forum. 2016. Shaping the Future of Construction: A Breakthrough in Mindset and Technology. Reference 220416. http://bit.ly/32ZLHAs.

Thank you