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A REVIEW PAPER ON 3D-PRINTING ASPECTS AND VARIOUS PROCESSES USED IN THE 3D-PRINTING

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Abstract-This is a research paper on 3D printing and the various materials used in 3D printing and their properties which become a notable topic in technological aspects. First, define what is meant by 3D printing and what is significant of 3D printing. We will go into the history of 3D printing and study about the process of 3D printing and what materials used in the manufacture of 3D printed objects and select the best materials among them which are suitable for our 3D printing machine. Also, see the advantages of 3D printing as compared to additive manufacturing.

I. INTRODUCTION

3D printing or additive manufacturing (AM) is a process formakinga3Dobjectofanyshapefroma3Dmodelorother electronic data sources through additive processes in which successive layers of material are laid down under computer controls. [1]Hideo Kodama of Nayoga Municipal Industrial Research Institute is generally regarded to have printed the first solid object from a digital design. However, the creditfor the first 3D printer generally goes to Charles Hull, who in 1984 designed it while working for the company he founded, 3D Systems Corp. Charles a Hull was a pioneer of the solid imaging process known as stereolithography and the STL (stereolithographic) file format which is still the most widely used format used today in 3D printing. He is also regarded to havestartedcommercialrapidprototypingthatwasconcurrent with his development of 3D printing. He initially used photopolymers heated by ultraviolet light to achieve the melting and solidification effect. [2]Since 1984, when thefirst 3DprinterwasdesignedandrealizedbyCharlesW.Hullfrom 3D Systems Corp., the technology has evolved and these machines have become more and more useful, while their price points lowered, thus becoming moreaffordable.

Nowadays, rapid prototyping has a wide range of applications in various fields of human activity: research, engineering, medical industry, military, construction, architecture, fashion, education, the computer industry and many others. In 1990, the plastic extrusion technology most widelyassociatedwiththeterm"3Dprinting"wasinventedby Stratasys by name fused deposition modeling (FDM). After the start of the 21st century, there has been a large growth in thesalesof3Dprintingmachinesandtheirpricehasbeen dropped gradually. By the early 2010s, the terms 3D printing andadditivemanufacturingevolvedsensesinwhichtheywere alternate umbrella terms for AM technologies, one being used in popular vernacular by consumer - maker communities and the media, and the other used officially by industrial AM end use part producers, AM machine manufacturers, and global technical standards organizations. Both terms reflect the simple fact that the technologies all share the common theme of sequential-layer material addition/joining throughout a 3D work envelope under automated control. Other terms that had been used as AM synonyms included desktop manufacturing, rapid manufacturing, and agile tooling on-demand manufacturing. The 2010s were the first decade in which metal end use parts such as engine brackets and large nuts would be grown (either before or instead of machining) in job production rather than obligatory being machined from bar stock orplate.

Fig. 1. 3D-printer

II. GENERALPRINCIPLES

A. Modelling

3D printable models can be created with the help of CAD design packages or via 3D scanner. The manual modeling process of preparing geometric data for 3D computergraphics is similar to method sculpting. 3D modeling is a process of analyzing and collecting data on the shape and appearance of anobject.Basedonthisdata,3Dmodelsofthescannedobject can be produced. Both manual and automatic creations of 3D printed models are very difficult for average consumers. That is why several market-places have emerged over the lastyears among the world. The most popular are Shape ways, Thing verse, My Mini Factory, andThreading.

B. Printing

Before printing a 3D model from .STL file, it must be processed by a piece of software called a "slicer" which converts the 3D model into a series of thin layers and produces a G-code file from .STL file containing instructions to a printer. There are several open source slicer programs exist, including, Slic3r, KISSlicer, and Cura. The 3D printer follows the G-code instructions to put down successive layers of liquid, powder, or sheet material to build a model from a series of cross-sections of a model. These layers, which correspond to the virtual cross sections from the CAD model, are joined or fused to create the final shape of a model. The main advantage of this technique is its ability to create almost any shape or geometric model. Construction of a model with existing methods can take anywhere from several hours to days, depending on the method used and the size and complexity of the model. Additive systems can typically reduce this time to very few hours; it varies widely depending on the type of machine used and the size and number of models being produced.

C. Finishing

Although the printer-produced resolution is sufficient for many applications, printing a slightly oversized version of the object in standard resolution and then removing material with a higher-resolution process can achieve greater precision. As with the Accucraft iD-20 and other machines Press Release. International Manufacturing Technology shows someadditive manufacturing techniques are capable of using multiple materials in the course of constructingparts.

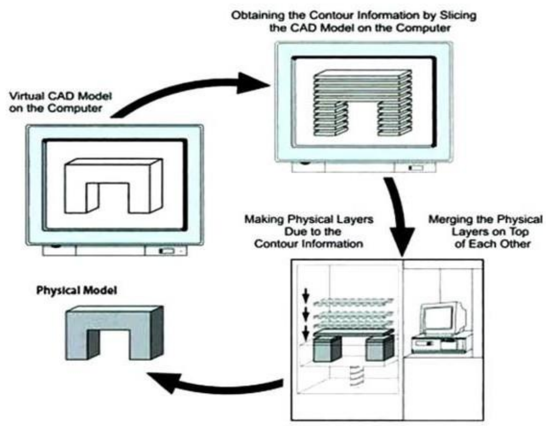

Fig. 2. Printing procedure

III. PROCESSES

Many different 3D printing processes and technologies have been invented from late 1970. The printers were originally very large and expensive in what they could produce.AlargenumberofAdditivemanufacturingprocesses are now available. Some of the methods melt or soften material to produce the layers, e.g. selective laser melting(SLM), selective laser sintering (SLS), fused deposition modeling (FDM), while others cure liquid materials using different other technologies, e.g. stereolithography (SLA) and With laminated object manufacturing(LOM).

A. Selective LaserSintering

Selectivelasersintering(SLS)wasdevelopedandpatented by Dr. Carl Deckard and academic adviser, Dr. Joe Beamanat the University of Texas in the mid-1980, under the sponsorship of DARPA.[2] Deckard was involved in the resulting start-up company DTM, established to design and build the selective laser sintering machines. In the year 2001, 3D Systems the biggest competitor of DTM acquired DTM. The most recent patent regarding Deckard's selective laser sintering technology was issued on January 1997 and expired on Jan 2014. Selective laser sintering is a 3D-printing technique that uses a laser as the power source to sinter powdered material (mostly metal), aiming the laser at points in space defined by a 3D model, binding the material tocreate a solid structure. Selective laser melting uses a comparable concept, but in SLM the material is fully melted thansintered, allowing different properties (crystal structure, porosity). SLS isarelativelynewtechnologythatsofarhasmainlybeenused for additive manufacturing and for low-volume production of parts. Production roles are expanding as the commercialization of additive manufacturing technology improves.

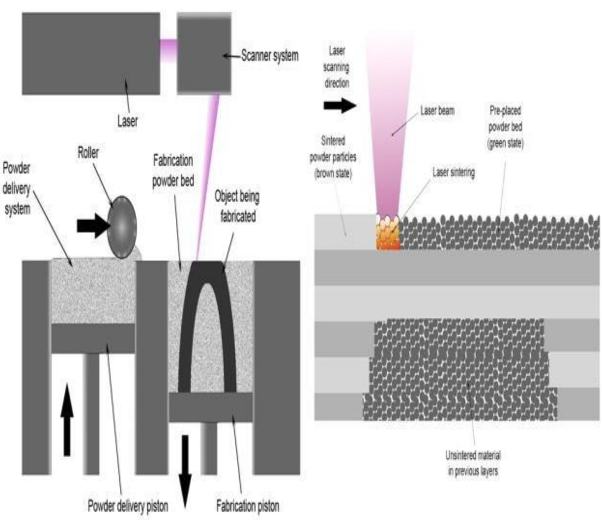

Fig. 3. Selective laser sintering

B. Fused DepositionMelting

Fused deposition modeling (FDM) method was developed by S. Scott Crump in the late 1980s and was designed in 1990 by Stratasys. After the patent on this technology expired, a large open source development community developed and commercialvariantsutilizingthistypeof3Dprinterappeared. As a result, the price of FDM technology has dropped by two orders of magnitude since its creation. In this technique, the modelisproducedbyextrudingsmallbeadsofmaterialwhich harden to form layers. A thermoplastic filament or wire thatis wound into a coil is unwinding to supply material to an extrusion nozzle head. The nozzle head heats the material up to the certain temperature and turns the flow on and off. Typically the stepper motors are employed to move the extrusionheadinthez-directionandadjusttheflowaccording totherequirements.Theheadcanbemovedinbothhorizontal and vertical directions, and control of the mechanism is done by a computer-aided manufacturing (CAM) software package running on amicrocontroller.

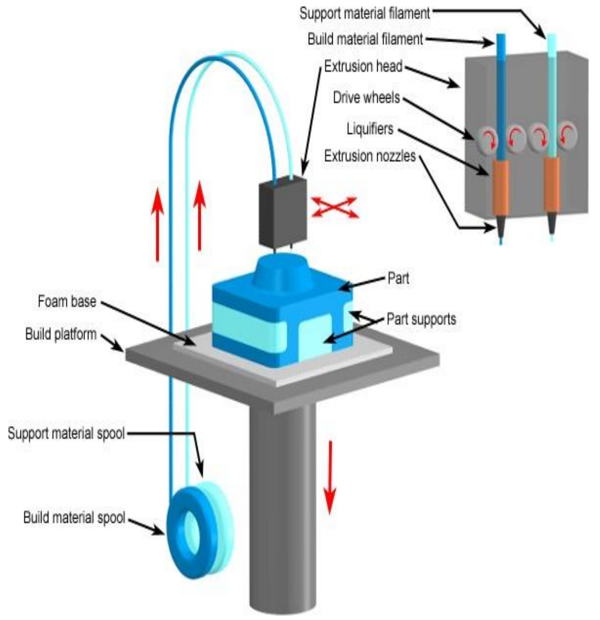

Fig. 4. Fused deposition modeling

C. Stereolithography

Stereolithography is an early and widely used 3D printing technology. 3D printing was invented with the intent of allowingengineerstocreateprototypesoftheirowndesignsin a more time and in an effective manner. The technology first appeared as early as 1970. Dr. Hideo Kodama Japanese researcher first invented the modern layered approach to stereolithography by using UV light to cure photosensitive polymers. On July 1984, before Chuck Hull filed his own patent and Alain Le Mehaute filed a patent for the stereolithography process. The French inventor's patent application was neglected by the French General Electric Company and by CILAS (The Laser Consortium). Le Mehaute believes that abandonment reflects a problem with innovation in France. Stereolithography is a form of 3-D printing technology used for creating models, prototypes, patterns in a layer by layer fashion using photo polymerization, a process by which light causes chains of molecules to link together, forming polymers.[1] Those polymers then make up the body of a three-dimensional solid.

Researchintheareahadbeenconductedduringthe1970s,but the term was coined by Charles (Chuck) W. Hull in 1986 when he patented the process. He then set up 3D Systems Inc. to commercialize hispatent.

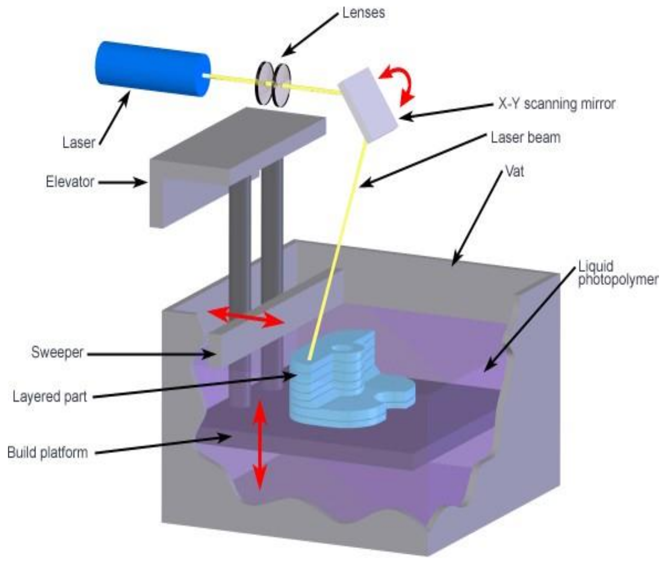

Fig. 5.Stereolithography

D. Laminated Object Manufacturing

It is a 3D-printing technology developed by Helisys Inc. (now Cubic Technologies). In it, layers of adhesive-coated paper, plastic, or metal laminates are successively joined together and cut to appropriate shape with a laser cutter. Objects printed with this technique may be additionally modified by machining after the printing process. the typical layer resolution for this process is defined by material feedstock and usually ranges in thickness from one to a many sheets of paper of a copy.

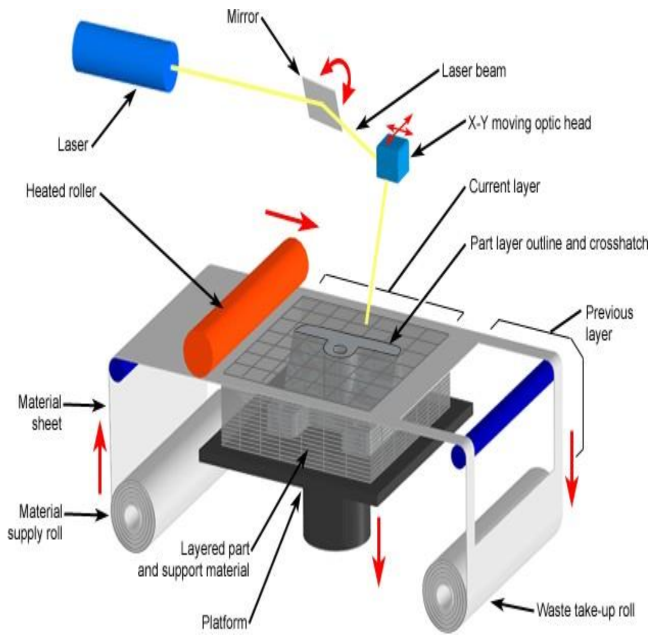

Fig. 6. Laminated Object Manufacturing

IV. 3D PRINTERMATERIAL

Following are the materials which can be used with the Accucraft i250 and their properties.

A. Acrylonitrile Butadiene Styrene[ABS]

One of the most widely used material since the inception of 3D printing. This material is very durable, slightly flexible, and lightweight and can be easily extruded, which makes it perfect for 3D printing. It requires less force to extrude than when using PLA, which is another popular 3D filament. This fact makes extrusion easier for small parts. The disadvantage of ABS is that it requires higher temperature. Its glass transitiontemperatureisabout105°Candtemperatureabout 210 - 250°C is usually used for printing with ABS materials. Also another drawback of this material is quite intense fumes during printing that can be dangerous for pets or people with breathing difficulties. So 3D printers need to be placed in well-ventilated area. Also good advice is to avoid breathing in fumes during printing considering the cost of 3D materials ABS is the cheapest, which makes it favorite in printing communities untilnow.

Technical Specifications:

- Density- 1-1.4gm/cm^3
- Dielectric constant- 3.1 to3.2
- Dielectric Strength [Breakdown Potential]- 15-16 kV/mm [0.59-0.63V/mil]
- Elastic modulus- 2 to 2.6GPa
- Elongation at break- 3.5 to50%
- Flexural modulus- 2.1 to 7.6GPa
- Flexural strength- 72 to 97 MPa
- Heat deflection temperature at 1.82 MPa -76 to 110°C
- Heat deflection temperature at 455 KPa- 83 to 110°C
- Strength to weight ratio- 37 to 79kN-m/kg
- Tensile strength: 37 to 110 MPa
- Thermal expansion- 81 to 95μm/m-K

Material Properties of Acrylonitrile Butadiene Styrene [ABS]

- Temperature -225°C
- Flow Tweak -0.93
- Bed Temperature -90°C
- Bed Preparation - apply glue stick 2 layer & then abs glue 1 layer

B. Poly Lactic Acid[PLA]

Poly lactic acid (PLA) (is derived from corn and is biodegradable) is another well-spread material among 3D printing enthusiasts. It is a biodegradable thermoplastic that is derived from renewable resources. As a result PLA materials are more environmentally friendly among other plastic materials. The other great feature of PLA is its biocompatibility with a human body. The structure of PLA is harder than the one of ABS and material melts at 180 – 220°C which is lower than ABS. PLA glass transition temperature is between 60 – 65 ° C, so PLA together with ABS could be some good options for any of yourprojects.

Technical Specifications

- Density - 1.3 g/cm³ (81 lb/ft³)
- Elastic (Young's, Tensile) Modulus - 2.0 to 2.6 GPa (0.29 to 0.38 x 10³psi)
- Elongation at Break - 6.0%
- Flexural Modulus - 4.0 GPa (0.58 x 10^{6}psi)
- Flexural Strength - 80 MPa (12 x 10³ psi)
- Glass Transition Temperature - 60 °C (140°F)
- Heat Deflection Temperature At 455 kPa (66 psi) - 65 °C (150°F)
- Melting Onset (Solidus) - 160 °C (320°F)
- Shear Modulus- 2.4 GPa (0.35 x 10^{6}psi)
- Specific Heat Capacity - 1800J/kg-K
- Strength to Weight Ratio - 38 kN-m/kg
- Tensile Strength : Ultimate (UTS) - 50 MPa (7.3 x 10³ psi)
- Thermal Conductivity - 0.13W/m-K
- Thermal Diffusivity -0.056

Material Properties of Poly Lactic Acid [PLA]

- Temperature -180°C
- Flow Tweak -0.95
- Bed Temperature -60°C
- Bed Preparation - apply glue stick 2layer

C. High Impact Polystyrene [HIPS]

HIPS filament is made from a High Impact Polystyrene material and it is another example of support 3d materials. This material is well spread in food industry for packaging. It is also used to pack CD discs and to produce trays in medicine naturally this filament has bright white color and it is also biodegradable so there is no adverse effect when it is put in tight contact with a human or animal body. HIPS filaments have curling and adhesion problems, which can be reduced by using a heated bed during the printing. HIPS material that can also be used as support structure during the printing and then dissolved in a colorless liquid hydrocarbon Solution.

Tech Specifications

- Density - 1.0 g/cm³ (62 lb/ft³)
- Dielectric Strength (Breakdown Potential) -18 kV/mm (0.7V/mil)
- Elastic (Young's, Tensile) Modulus -1.9 GPa (0.28 x 10^{6}psi)
- Elongation at Break - 40%
- Flexural Strength - 62 MPa (9.0 x 10³ psi)
- Glass Transition Temperature - 100 °C (210°F)
- Heat of Combustion (HOC) - 43MJ/kg
- Limiting Oxygen Index (LOI) - 18%
- Poisson's Ratio -0.41
- Specific Heat Capacity - 1400J/kg-K

- Strength to Weight Ratio - 32 kN-m/kg
- Tensile Strength: Ultimate (UTS) - 32 MPa (4.6 x 10^3 psi)
- Thermal Conductivity - 0.22W/m-K
- Thermal Diffusivity -0.16
- Thermal Expansion - 80µm/m-K
- Vicat Softening Temperature - 110 °C (230°F)
- Water Absorption After 24 Hours -0.08%

Material Properties of High Impact Polystyrene [HIPS]

- Temperature -225°C
- Flow Tweak -0.91
- Bed Temperature -90°C
- Bed Preparation - apply glue stick 2 layer & thenabs glue 1 layer

V. ADVANTAGES

1. Time-to-Market: 3D printing allows ideas to developfaster. Being able to print a concept on the same day it was designed shrinks a development process from what might have been months to a number of days, helping companies stay one step ahead of theother.

2. Save Money: Prototyping injection mould tools and production runs are expensive investments. The 3D printing process allows the creation of parts and/or tools through additive manufacturing at rates much lower than traditional machining.

3. Mitigate Risk: Being able to verify a design before investing in an expensive moulding tool is worth its weight in 3D printed plastic, and then some. It is far cheaper to 3D print a test proto type than to redesignor alter an existing mould.

4. Feedback: With a prototype, you can test the market by unveiling it at a tradeshow, showing it to buyers or raising capital by pre-selling on Indigo or Kick-starter. Getting buyer's response to the product before it actually goes into production is a valuable way to verify the product has market potential.

5. Get the Feel: One thing you can't get a picture or virtual prototype on the computer screen is the way something feels inyourhand.Ifyouwanttoensuretheergonomicsandfitofa product are just right, you must actually hold it, use it and test it.

6. Personalize It: With standard mass-production, all parts come off the assembly line or outof the mould the same. With 3D printing, one can personalize, customize a part touniquely fit their needs, which allows for custom fits in the medical industries and helps set people to elaborate their idea in new world.

7. Build your Imagination: In the modern boom of digital art and design, the possibilities are not only accelerating but limitless. One can now 3D prints almost everything they imagine after drawing it up virtually or by other. In a relatively short time, an idea, concept, dream or invention can go from a simple thought to a producedpart.

8. Square Holes? No Problem: The limitations of standard machininghaveconstrainedproductdesignforyears.With the improvements in AM, now the possibilities are endless. Geometry that has been historically difficult to build; like holes that change direction, unrealistic overhangs is now possible and actually simple to construct.

9. Fail Fast, Fail Cheap: 3D printing allows a product developer to make breakthroughs at early stages that are relatively inexpensive leading to better products and less expensivedead-ends.

VI. DISADVANTAGES

1. Intellectual property issues: The ease with which replicas can be created using 3D technology raises issues over intellectual property rights. The availability of blueprints online free of cost may change with for-profit organizations wanting to generate profits from this newtechnology.

2. Limitations of size: 3D printing technology is currently limited by size constraints. Very large objects are still not feasible when built using 3Dprinters.

3. Limitations of raw material: At present, 3D printers can work with approximately 100 different raw materials. This is insignificant when compared with the enormous range of raw materials used in traditional manufacturing. More research is required to devise methods to enable 3D printed products to be more durable androbust.

4. Cost of printers: The cost of buying a 3D printer still does not make its purchase by the average householder feasible. Also, different 3D printers are required in order to print different types of objects. Also, printers that can manufacture in colour are costlier than those that print monochrome objects.

5. Fewer Manufacturing Jobs: As with all new technologies, manufacturing jobs will decrease. This disadvantage can have a large impact to the economies of third world countries especially China, that depend on a large number of low skill jobs.

6. Unchecked production of danger items: Liberator, the world's first 3D printed functional gun, showed how easy it was to produce one's own weapons, provided one had access to the design and a 3D printer. Governments will need to devise ways and means to check this dangeroustendency.

VII. APPLICATIONS

1. The Aeronautics and Aerospace industries push the limits of geometric design complexity; the evolution and consistent improvement of the vehicles demand that the parts become more efficient and accurate even as the size of the vessels become smaller. This is why design optimization is essential to the progression of the industry. Optimizing a design can be challenging when using traditional manufacturing processes,

andthat'swhymostengineershaveturnedto3DPrinting.

2. To support new product development for the medical and dental industries, the technologies are also utilized to make patterns for the downstream metal casting of dental crowns and in the manufacture of tools over which plastic is being vacuum formed to make dentalaligners.

3. For the jewellery sector, 3D printing has proved to be particularly disruptive. There is a great deal of interest and uptake based on how 3D printing ca n, and will, contribute to the further development of this industry. From new design freedoms enabled by 3D CAD and 3D printing, through improving traditional processes for jewelry production all the way to direct 3D printed production eliminating many of the traditional steps.

4. Architectural models have long been a staple application of 3D printing processes, for producing accurate demonstration models of an architect's vision. 3D printing offers a relatively fast, easy and economically viable method of producing detailed models directly from 3D CAD, BIM or other digital data that architectsuse.

5. As 3D printing processes have improved in terms of resolutionandmoreflexiblematerials,oneindustry,renowned for experimentation and outrageous statements, has come to the fore. We are of course talking about fashion.3D printed accessories including shoes, headpieces, hats, and bags have all made their way on to globalcatwalks.

CONCLUSION

Introduction part is about the brief history of 3D printing, in the next section we have depicted the 3D-printing and the processes used in 3D-printing and the properties of the 3D- printer materials. In the third section, we have highlighted the main advantages and limitations of the 3D printing technology. One can conclude that the 3-D printing technology's importance and social impact increase gradually day by day and influence the human's life, the economy, and modern society.

3D Printing technology could revolutionize the world. Advances in 3D printing technology can significantly change and improve the way we manufacture products and produce goods worldwide. An object is scanned or designed with Computer Aided Design software, then sliced up into thin layers, which can then be printed out to form a solid three-dimensional product. As shown, 3D printing can have an application in almost all of the categories of human needs as described by Maslow. While it may not fill an empty unloved heart, it will provide companies and individuals fast and easy manufacturing in any size or scale limited only by their imagination. 3D printing, on the other hand, can enable fast, reliable, and repeatable means of producing tailor-made products which can still be made inexpensively due to automation of processes and distribution of manufacturing needs.

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