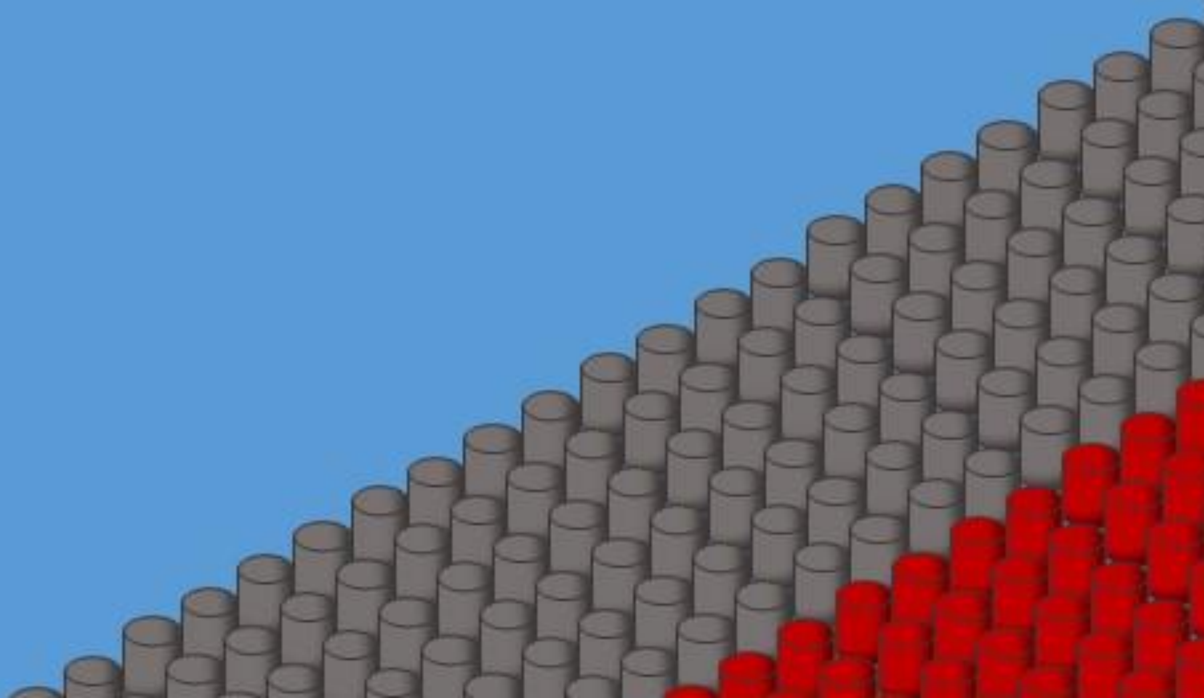
Addibots

Addibots®

Making the World a Workspace



What is an Addibot®?

Addibot®s change the way we make things by creating new additive manufacturing applications and products. Additive manufacturing (AM), colloquially called 3D printing, is a relatively new, rapidly expanding field that has pioneered powerful and innovative manufacturing methods. Still, current 3D printing methods have limitations. By combining AM technology with mobile robotics, Additive Manufacturing Robots, or Addibots, a patent pending new technology, will break free from these limitations.

Mobilizing the Workspace

In the simplest of terms, an Addibot® may be described as a 3D printer mounted onto a moving robot, to create a mobile interface for AM. Although a very simple concept in these terms, this "mobile AM interface," or the ability to move AM implements to any desired location in space, solves central issues and limitations inherent with current 3D printing technologies and methods.[1]

A central limitation of current 3D printing methods is the fact that they operate inside a workspace of finite dimensions. Since a typical 3D printer consists of AM implements moved about on slides mounted inside of a 'box' printing workspace (often literally an enclosed box in commercial 3D printers), the printer is not able to construct objects outside of the dimensions of its workspace. For many household 3D printers, these dimensions are merely a few inches in each direction. For these printers, larger objects can only be manufactured with larger printers, making the fabrication of sizable industrial products either incredibly expensive (due to astronomical equipment costs) or downright impossible (for objects, like buildings or bridge trusses, just too large for a printer of this type). To an Addibot, however, this a trivial dilemma; by utilizing the mobile AM interface, methods for printing objects function the same at any scale. The ability for an Addibot to move its printing implements to any desired location in space allows it to break free from the restrictions of the finite printing workspace.

Solving this central issue of current 3D printing methods, however, is just the beginning. The true power of the Addibot® concept lies not only in breaking free from spatial limitations of the traditional workspace, but in mobilizing, and thus completely redefining, the workspace. By nature of their methodology, traditional 3D printers utilize materials to fabricate objects designed to be taken out of the workspace upon completion; the mobility of an Addibot, however, allows for any surface to become a workspace, so an Addibot can use materials that integrate *into* the desired workspace. As a result, Addibots help AM become more than just constructing 3D objects, and open up the floor for myriad new application spaces for AM.

Endless Applications

By using materials that integrate into surfaces, a first set of new application spaces arises where workspace surfaces become part of the construction, rather than merely serving as a location for the print. Many constructed surfaces exist in our world: for infrastructure, displaying images or advertising, separating functional spaces, and the list goes on. Of course, these surfaces are subject to wear and may suffer damage over their lifetime that causes defects. Many methods that exist for repairing surface defects, such as with road repair for example, require laborious and/or slow methods with relatively imprecise machinery. Coupling computer vision capabilities with high resolution and precision AM implements, an Addibot is the perfect tool for many resurfacing applications, to either improve upon the methods or results of existing resurfacing applications, or to make new applications possible. With road repair for example, Addibots can

[1] A quick look now at Appendix – "A Brief Overview of Common 3D Printing Methods" will provide helpful context to readers not familiar with the basic principles of common AM methods.

drive down a road and sense cracks or pot holes while laying down material to fill and repair these defects at a constant driving speed. As well, with the same overall additive methods, Addibots are also able to construct entirely new surfaces, rather than just repairing them.

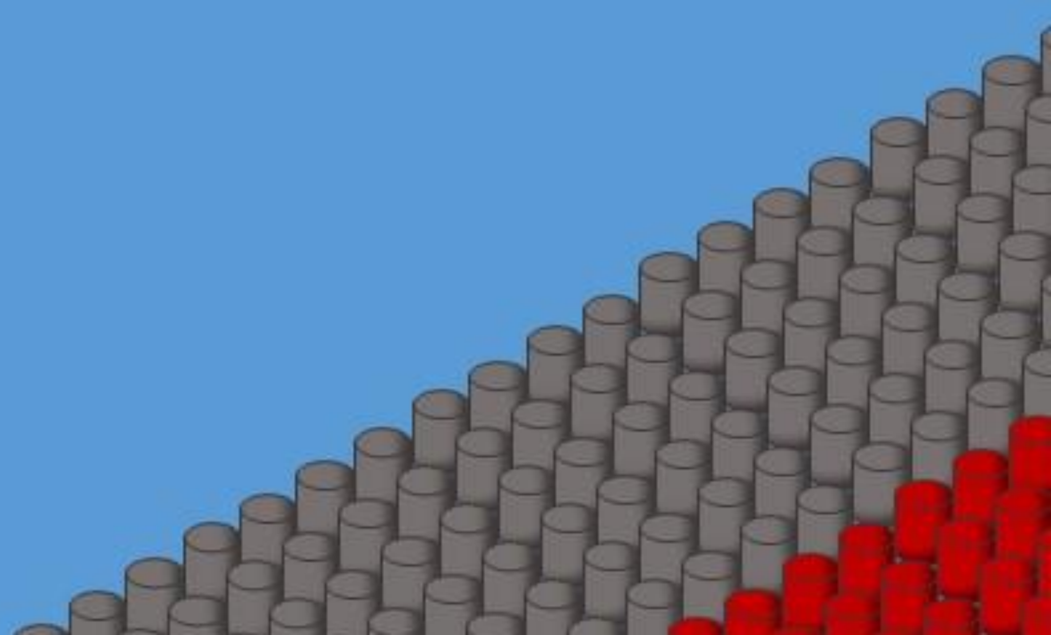
Up to this point in the discussion, due to established methods of printing within a confined workspace of a single printer, readers (especially those knowledgeable in AM) may be envisioning a solitary Addibot tackling printing jobs for the application space of their design. While it is possible for an Addibot to work alone, another powerful result of the Addibot® concept is the possible teamwork between multiple Addibots within a single workspace and on the same job. By having more than one Addibot working on any of the printing jobs mentioned in this document, significant efficiencies arise with regards to finishing overall tasks more quickly (with more 'workers' laying down material), individual units needing to carry less material, etc. However, an entirely new set of application spaces arises when considering using multiple Addibots with different materials each in a single job. For example, a team of Addibots, one with a plastic material for a shell or casing, one with a strong metal for heavy structural members, one with a lighter metal for less stressed members, and other Addibots with other materials as necessary, could construct a complex multi-material boat hull, bridge truss, or other objects composed of these materials. Teams of Addibots printing multi-material structures could even do so in surface repair or construction applications; again considering Addibots used to construct roads, in addition to having Addibots lay down tar and mineral aggregates used in normal bituminous road constructions, other Addibots could print carbon nanotubes or fibers for additional strength, lay down conductive materials to route electricity or communications through the road, or even incorporate sensors into the road, among other possible materials added to the construction.

A further strength of the Addibot® concept lies in considering the control scheme of the Addibots themselves. Addibots may be controlled by users directly, autonomously, or with varying degrees of both, depending on the specific application. With AM implements outside of the controlled 'box' workspace, Addibots may print in dynamic environments, such as with repairing irregular surface defects, where autonomous methods would excel. In certain surface construction applications, however, a user may desire the ability for the Addibot to print from a pre-programmed model, or to be directed by them during the print. With other applications, both autonomous and pre-programmed/directed control would be desired; for example, Addibots could be used to construct a statue in a park, where the Addibots autonomously construct a level base that bonds with the surface the statue will sit on, and then print the statue on this base according to a computer model. Alternatively, again considering road engineering with Addibots, an engineer may direct the motion of one Addibot that 'leads', or directs, the motion of other autonomous Addibots during a print.

In Summary

An Addibot® is a patent pending combination of a robot and a 3D printer to achieve a mobile interface for AM. This mobile interface allows for the free movement of AM implements in space to print objects of arbitrary size, eliminating the size restrictions of the traditional 'box' 3D printing workspace. Addibots may print on existing or otherwise pre-processed surfaces, with a single or multiple materials that can integrate with these surfaces, while working alone or in teams with controlled or autonomous methods to bring the field of AM to an endless multitude of new application spaces. Addibots mark a paradigm shift in AM technology, breaking free from the confines of the 3D printing workspace to make the world a workspace.

Addibots®



Appendix – “A Brief Overview of Common 3D Printing Methods and Materials”

Additive Manufacturing (AM), colloquially known as 3D printing, may be understood most simply as the creation of 3D objects by means of coordinated distribution of material, often from a digital model. The creation of these objects typically consists of bonding together multiple horizontal cross-sectional layers of the desired object. The technological advancement of AM to this point has primarily focused on developing either methods of 3D printing or finding new materials to be used with AM methods. Depending on the specific application, the workspace conditions for these different methods could be modified for use with Addibots.

Methods

In 2010, the ASTM (American Society for Testing and Materials) set standards for classifying the different methods for 3D printing[2]. As this classification stands in the state of the art of today, there are 7 main methods for AM. Below are these 7 classifications with terminology as defined by the ASTM, as well as a brief discussion[3] of each.

Binder Jetting

“an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials.”

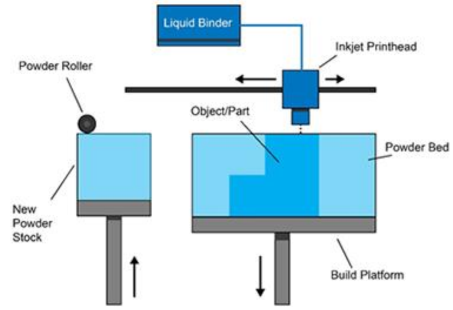


Diagram of exemplary binder jetting

With binder jetting, a powdered base material (as the main piece material) is selectively treated with a bonding agent based on a digital model. Typically, the bonding agent is applied to a top layer of the powdered base material. Wherever the bonding agent is applied, the powdered base material coagulates to form a cross sectional layer of the object. When the bonding agent has been applied to a whole layer, a new layer of powdered base material is spread over the previous layer, and this process is repeated so that new layers bond to previous layers to create a desired object. This method is generally faster than others, however objects are typically porous and have low structural integrity, requiring post-processing for use in certain applications. Common materials used with this method include metals, polymers, and ceramics.

Directed Energy Deposition

“an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited.”

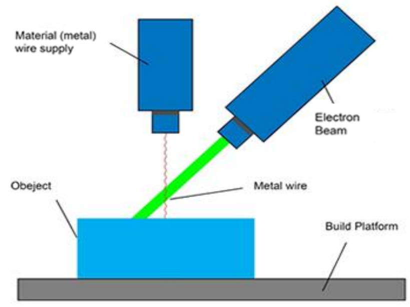


Diagram of exemplary directed energy deposition

With directed energy deposition (DED), a material (typically in the form of a wire or powder) is deposited onto an object within a workspace and then melted by a directed energy beam, to bond to the object. The implements within a DED machine are typically mounted to 4 or 5 axis arms for highly controlled placement of the deposited material. This method has be used to repair objects or to add material to objects, not just construct them, but often requires post-processing of some kind. Common materials used with this method include polymers and ceramics, but most typically metals fed in wire form.

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[2] ASTM 7 Methods: http://www.astm.org/FULL_TEXT/F2792/HTML/F2792.htm

[3] Images, quotes, and source for discussion: http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/

Material Extrusion

"an additive manufacturing process in which material is selectively dispensed through a nozzle or orifice."

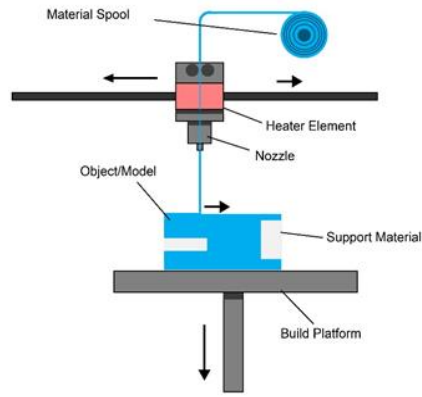

Diagram of exemplary material extrusion

With extrusion, also known as Fusion Deposition Modeling (FDM), a printing material (often in the form of a solid wire) is fed through an extrusion head, where thermal processing (or other types of processing) induces a change of state from solid to a fluid. The extrusion head then moves to deposit this material based on a digital model in a cross-sectional layer. When a layer is complete, the extrusion head moves up to print on top of the previous layer, repeating the method to fuse the subsequent layers together and create a 3D object from the bottom, up. FDM benefits from having typically cheaper material processing then other methods, as well as being easier for users to understand, and is possibly the most common method for household 3D printers. FDM methods may use multiple extrusion heads at once, for example, using a base material as well as a support material that can be dissolved away during post-processing, to create more complex objects. Common materials used by this method include polymers and plastics.

Material Jetting

"an additive manufacturing process in which droplets of build material are selectively deposited."

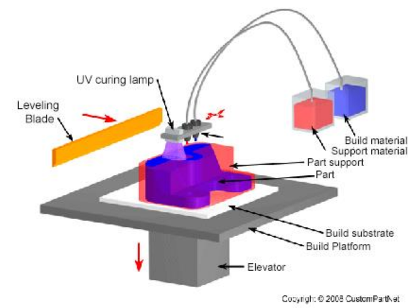

Diagram of exemplary material jetting

With material jetting, a liquid printing material is fed to a deposition element that jets the material onto a build surface in a controlled manner, based on a digital model. Through thermal processing, UV curing, or other methods, the jetted material is hardened on the injection site. This process is done for a single layer at a time, and repeated to build an object layer by layer, similar to extrusion (FDM). Material jet printers may contain multiple materials, such as a main build material and a support material, for example, to build complex objects. Common materials used with this method include polymers and plastics.

Powder Bed Fusion

"an additive manufacturing process in which thermal energy selectively fuses regions of a powder bed."

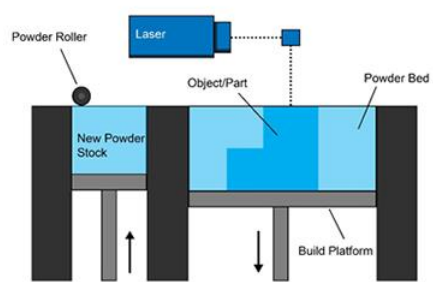

Diagram of exemplary powder bed fusion

With powder bed fusion, a powdered base material is selectively processed with a directed energy beam, based on a digital model. This processing consists of melting the powder particles, making them fuse to surrounding material. Similarly to binder jetting, the top layer of loose powder is processed at a single time. After the completion of that layer, a new layer of powdered material is spread on top of the previous layer; as material in that layer is processed, it also fuses to the previous layer, repeating this process to build a solid object. A common form of this is called 'sintering,' where powdered metals are deposited and then melted to create objects with high energy beams or even focused light. Common materials used with this method include any powdered materials, but most commonly includes metals or polymers.

Sheet Lamination

"an additive manufacturing process in which sheets of material are bonded to form an object."

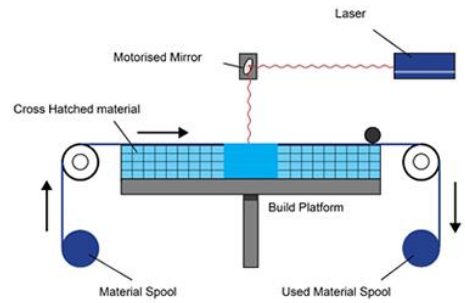

Diagram of exemplary sheet lamination

With sheet lamination, sheets of a build material or materials are bonded together during processing. This method suits any material that may be formed into sheets. Typically, objects produced by this method require post-processing with destructive methods, like CNC milling, to form the final piece. This method is very effective for producing objects with multiple different materials among the layered planes. Common materials used with this method include metals and papers. When metals are used, the bonding of layers may be achieved through ultrasonic welding.

Vat Polymerization

"an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization."

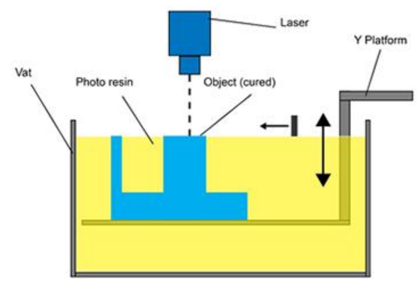

Diagram of exemplary vat polymerization

With vat polymerization, a vat containing a liquid polymer and a moving platform is processed with a UV laser. The platform is arranged so that the amount of liquid above the platform is equivalent to the desired layer thickness of the part, upon which point the UV laser cures the polymer so that it hardens and solidifies. Upon the completion of the first layer, the platform lowers a single layer thickness, and the curing process is repeated to build a second layer on top of the first; the lowering and curing process is repeated for each of the layers to construct the object. Although the process of curing the polymer to create the object may be quite rapid (and even continuous with sophisticated UV laser technology), lengthy post-processing is required for the polymers used in this process. Although this method specifically covers polymerization with UV light, the overall process flow may also be extrapolated to super-saturated solutions, such as with sugars, or other types of solutions, where an energized laser excites the solution, causing material to fall out of solution and solidify, similarly to how the polymers cure and harden in UV light.

Materials

A large component of development within the AM industry has included advancing not only the methods possible for 3D printing, but also the materials that can be used. The following list consists of materials that have been cited to have been successfully used in commercial or laboratory settings with AM methods[4][5]. This list is not complete and is constantly evolving as new materials are utilized.

- Chocolate
- Wood
- Concrete
- Organic cells/tissues
- Adhesive papers
- Paper
- Silica/Glass
- Graphene
- Brass
- Sandstone
- Porcelain
- Silicon-Carbide

[4] http://www.lboro.ac.uk/research/amrg/about/materials/
[5] http://www.shapeways.com/materials

- Steel
- Titanium
- Stainless steel
- Cobalt chrome alloy
- Aluminum
- Gold
- Silver
- Polycarbonate
- ABS
- Nylon
- PLA
- Epoxy resin
- Wax
- Photopolymer resins
- Filament mixtures of above materials