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(54) **Title:** SYSTEM AND METHOD FOR LAYER BY LAYER PRINTING OF AN OBJECT WITH SUPPORT

(57) **Abstract:** A system and method of constructing an object layer by layer by applying a material in a liquid state to a first layer, selectively curing to a solid state pre-defined areas of the first layer, where such areas match the coordinates of the object in such layer, and leaving in an uncured state, areas of the layer that are not included in the object in such layer. The uncured areas of the layer that surround the cured areas are cooled and hardened to provide support for the object as it is being constructed. The uncured supporting material in the layer may be removed when the construction of the object is completed.

SYSTEM AND METHOD FOR LAYER BY LAYER PRINTING  
OF AN OBJECT WITH SUPPORT

FIELD OF THE INVENTION

[001] The present invention relates to layer by layer formation of an object and selective curing of materials used in such formation.

BACKGROUND OF THE INVENTION

[002] Layer by layer or three-dimensional (3D) object formation enables the formation and construction of objects through the layer by layer application of materials, and the curing, adhesion or fusion of areas of the object in the successive layers. The structure or shape of objects created through such processes may include overhangs, or parts of the object in an upper layer that require a supporting lower layer or layers for a portion of the object being formed in said upper layer. It may therefore be advisable to deposit a temporary support area in a lower layer that will support a portion of an upper layer as is it formed. The temporary support in such lower layer may be removed once the object is formed or at some other time. The deposit of such a support material may complicate a process of forming an object, and may entail added expense as different materials may be deposited or used for the support and for the build portions of the object being constructed.

SUMMARY OF EMBODIMENTS OF THE INVENTION

[003] Embodiments of the invention may include a system for layer by layer printing of an object, where such system includes an applicator for applying a layer of a material in a liquid form onto a printing surface, e.g. a printing tray upon which an object is to be printed layer by layer; and a source of energy to selectively cure and harden a pre-defined area of the applied layer of material, where the pre-defined area corresponds to a location, volume or set of coordinates of the intended object in the applied layer. A remaining area or areas of the layer which are not reached by the source of energy are left uncured and may be

hardened e.g. by cooling to be both suitable to support the pre-defined cured area/s in the subject layer as well as layers above the subject layer, and be subsequently easily removable.

[004] In some embodiments, a system may include an elevated pad on the printing tray where the pad approximates a footprint of the object. In some embodiments, a system may include an elevator to raise or lower a level of the applicator relative to the printing tray so as to engage a top surface of the elevated pad or layers of material printed above the elevated pad. In some embodiments, a system may include a cooling unit to cool and thus harden the uncured area or areas of an applied layer relatively quickly after the curing of a pre-defined area of the applied layer is completed. In some embodiments, the applicator may be or include a roller or series of rollers to apply the material to an upper surface of the tray or of the object being printed on the tray. In some embodiments, a system may include a heater to heat the material prior to its application to a surface.

[005] Embodiments of the invention may include a method of forming an object layer by layer, where the method includes applying a layer of a material to a platform or surface upon which the object is to be printed; selectively curing a pre-defined area of the applied layer, where the pre-defined area corresponds to the coordinates of a layer of the object in the applied layer, and leaving uncured an area of the same applied layer surrounding the pre-defined cured area; and cooling and thus hardening the uncured material of the applied layer surrounding the pre-defined area to be able to support the cured pre-defined area in the subject layer and areas in new upper layers of the object that are to be applied and cured and/or otherwise solidified in subsequent layers deposited at higher elevations in the Z axis. In some embodiments, the cooling and thus hardening of uncured material may include blowing air onto the applied layer.

[006] In some embodiments, applying a new liquid material layer may include bringing a roller bearing the material to be applied into contact with the upper surface of the printing tray, elevated pad/s or upper surface of the block of applied material and applying the liquid material to the upper surface to provide a new layer, i.e. a new upper surface. In some embodiments, a method may include heating the material prior to the roller's applying of the material. In some embodiments, a method may include removing uncured material upon completion of printing the object. In some embodiments, applying the material may include applying the material to an elevated pad on a platform upon which the object is to be

printed. In some embodiments, applying the material may include applying the material only to a surface over the elevated pad. In some embodiments, a method may include shaping the pad to conform to a footprint of the object. In some embodiments, a method may include applying a dimension of the footprint to a cutting or preparation of the pad. In some embodiments, a method may include limiting the application of layers of the material only to an area over the elevated pad or platform.

[007] Embodiments of the invention may include a device such as a pad to elevate an area of a printing surface for layer by layer printing or formulation of an object, where the elevated area is above the printing surface, and where contact of a material applicator is limited to the elevated area. In some embodiments, the shape of the area may correspond to a footprint of the object.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[008] The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with features and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanied drawings in which:

[009] Figs. 1A, 1B and 1C are side views of a system for layer by layer construction of an object, where such figures depict various positions of a cycle of depositing a layer of material, in accordance with an embodiment of the invention;

[010] Figs. 2A and 2B are schematic side and top views, respectively, of an object being constructed layer by layer, where the object is surrounded and supported by supporting material, in accordance with an embodiment of the invention;

[011] Figs. 3A and 3B are schematic side and top views, respectively, of objects being constructed layer by layer, where the objects are surrounded and supported by a reduced volume of supporting material, in accordance with an embodiment of the invention;

[012] Figs 4A and 4B are schematic side and top views of objects being fabricated layer by layer on an elevated pad, in accordance with an embodiment of the invention;

[013] Figs. 5A and 5B are schematic side and top views of a set of objects, each being fabricated layer by layer on a separate elevated pad, using a reduced volume of supporting material, in accordance with an embodiment of the invention;

[014] Figs. 6A and 6B are schematic side and top views of a set of objects, each being fabricated layer by layer on a separate elevated pad, where a shape of each pad approximates an outline of the object being constructed, in accordance with an embodiment of the invention;

[015] Figs. 7A and 7B are schematic side and top views of a set of objects, each being fabricated layer by layer on a separate elevated pad, where layer by layer construction of one of the objects has ceased at a lower layer than a construction of the other object, in accordance with an embodiment of the invention;

[016] Fig. 8 is a flow diagram of a method in accordance with an embodiment of the invention; and

[017] Fig. 9 is a flow diagram of a method in accordance with an embodiment of the invention.

[018] It will be appreciated that for simplicity and clarity of illustration, elements shown in the drawings have not necessarily been drawn accurately or to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity or represent several physical components included in one functional block or element. Further, where considered appropriate, reference numerals may be repeated among the drawings to indicate corresponding or analogous elements. Moreover, some of the blocks depicted in the drawings may be combined into a single function.

#### DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[019] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those of ordinary skill in the art that the present invention may be practiced without these specific details. Various modifications to the described embodiments will be apparent to those with skill in the art, and the general principles defined herein may be applied to other embodiments. Therefore, the present invention is not intended to be limited to the particular

embodiments shown and described, but is to be accorded the widest scope consistent with the principles and novel features herein disclosed. In other instances, well-known methods, procedures, components and circuits may not have been described in detail so as not to obscure the present invention.

[020] The term "layer" is used throughout the specification and claims to describe any lamina, film or deposit of material that may represent a cross-section or slice of a three-dimensional (3D) object. A layer may be formed and adhere to previously formed and adhered layers in a "layer by layer" fashion to create, build up or form the 3D object. A layer may be deposited in for example a liquid or some other state.

[021] The terms "X direction" and "Y direction" as used throughout the specification and claims refer to directions horizontal to a printing tray or surface that are indicative of relative movement between a dispensing head or other portion of an applicator and the printing tray or surface during selective deposition of material via nozzles, rollers or other dispensing devices onto a printing tray. The relative movement may be achieved by moving an applicator while the tray is kept motionless, by moving the printing tray while keeping the applicator motionless or by moving both the applicator such as the rollers and the printing tray relative to one another. The term "Z direction" as used herein throughout the specification and claims refers to a direction perpendicular to both the X and Y directions. The Z direction is indicative of the vertical direction in which the consecutive layers are formed.

[022] Reference is made to Fig. 1A, a side view of a system 100 for layer by layer construction of an object, in accordance with an embodiment of the invention. A system 100 may include a carriage 128 with a printing tray 124 on to which a material applicator system 180 may deposit liquid material 170. Material 170 may be heated to a first temperature e.g.  $>50^{\circ}\text{C}$  to achieve and/or maintain a liquid state. Material 170 may be collected by roller 156 from a fluid material bath 152, and may exchange material 170 with roller 136 that may spread material 170 as an upper surface material layer 122S onto block 122. Material applicator system 180 may move back and forth over block 122 spreading material 170 over the upper surface 122S of block 122 as it passes. Alternatively, carriage 128 bearing tray 124 and block 122 being constructed may move back and forth under material application system 180 such that application system 180 comes into contact with the upper surface of tray 124 or upper surface 122S of block 122 and spreads material over

said surface as it passes, to form a layer of material. System 100 may also be associated with a projector 104 that emits or transmits beams 112, i.e. directed beams 114 or other energy onto layer 122S. A processor 132 may control and direct beams 114A and 114B respectively, to cure and solidify the predefined areas, volumes or coordinates of layer 122S at those points in layer 122S where object 120A and object 120B are to be formed, while leaving the remainder of layer 122S uncured. A blower 164 may move with or behind applicator 180 to cool and thus harden the uncured parts of layer 122S once the pre-defined areas that include object 120 have been cured. A cured area may be permanently hardened while an uncured area may be cooled to a hard or solid state, but may melt or soften once heat is reapplied.

[023] In operation, processor 132 may receive for example a bitmap of a layer 122S of block 122 that includes the pre-defined areas in such layer 122S that are to form part of objects 120A and 120B. Material 170 may be heated in bath 152 to achieve a liquid state, and roller 156 may roll in bath 158 to collect a continuous layer of liquid material 170 that may be spread onto roller 136. Roller 136 may be raised to a level slightly above a top surface 122S of block 122 and may be rolled across such top surface by a movement of applicator 180 over the top surface, thereby spreading a new upper layer 122S of liquid material 170 along a top of block 122. Processor 132 may direct projector 104 to direct beams 114 of energy onto only those areas of layer 122S that are indicated in the received bitmap to become part of object 120 (e.g. 120A and 120B), and directed beams 114 may cure, harden and solidify such areas. The rest of surface layer 122S that was not cured by beams 114 may remain uncured, and may be cooled and hardened by a pass of blower 164 or by exposure to ambient air (e.g. 20° – 50°C) to achieve a consistency that may provide support 116 for both the cured areas of layer 122S and for overhanging areas in upper layers of block 122 that are to be deposited in later passes of applicator 180 over block 122 and are higher up on the Z axis of block 122. This process may be repeated for such higher layers of block 122 until objects 120A and 120B are formed. The hardened supporting material forming support 116 may be removed, e.g. by melting, from the objects 120A and 120B after construction of the objects is completed.

[024] The use of a single photocurable material 170 that includes both a wax-like substance that is at least semi solid or solid when cooled, as well as a photopolymer which hardens when cured by a source of energy, may facilitate the hardening by curing of certain pre-defined areas of layer 122S, while the uncured areas of such same layer 122S remain

liquid until cooled and hardened by exposure to cooling air, e.g. from blower 164 or the ambient temperature.

[025] In some embodiments, carriage 128 may be associated with or connected to a mechanism (not shown) that moves carriage 128 under the control or in coordination with a processor 132. Such movement may be in for example an  $\pm X$  and  $\pm Z$  directions as illustrated.

[026] In some embodiments system 100 may include a device such as projector 104 for selective delivery of electromagnetic (EM) radiation and/or synergistic stimulation. Projector 104 may include a mask and/or a projection unit to deliver the EM radiation and/or synergistic stimulation selectively to the defined area/s or volume/s of material in layer 122S to be solidified. EM radiation and/or synergistic stimulation can be selectively delivered to the upper layer of the object being built or parts thereof by means of further suitable components, including but not limited to optical elements, lenses, shutters, voxel matrix projectors, bitmap generators, mask projectors, mirrors and multi-mirror elements and the like. Examples of suitable radiation techniques to selectively deliver electromagnetic radiation and/or synergistic stimulation include, but are not limited to spatial light modulators (SLMs), projection units on the basis of Digital Light Processing (DLP.RTM.), DMD.RTM., LCD, ILA.RTM., LCOS, SXRD, etc., reflective and transmissive LCDs, LEDs or laser diodes emitted in lines or in a matrix, light valves, MEMs, laser systems, etc. Use of a DLP mask projector is preferred. Defined area/s or volume/s of material 170 forming upper layer 122S is subjected to selective EM radiation or synergistic stimulation and thus cured to form a new layer of the object 120 being built.

[027] Tray 124 may be situated on carriage 128 to provide a fabrication or printing surface upon which an object may be printed or constructed. Tray 124 may be detachable from carriage 128 so that it may be moved, removed or replaced with another tray, and so that an object whose construction has been completed or otherwise suspended may be moved or removed from system 100 with or on tray 124. Printed block 122 may include one or more objects being constructed in layer by layer application of materials, such as model 120A and model 120B. Models 120A and 120B may be surrounded and supported by support 116. Support 116 may be removed or separated from model 120A and model 120B after the completion of construction of models 120A and 120B. Block 122 may be formed layer-by-

layer, where a current layer is printed or applied on top of upper surface 122S of a previous layer.

[028] Processor 132 may control the operation of system 100, such as carriage 128 and projector 104. Processor 132 may utilize for example a computer aided design (CAD) program that may reside on a CAD computer 130 external to and separate from system 100 or as part of system 100, and which may be used to for example design model 120A and model 120B, and to transform the design into digital representation of cross-sectional layers of the models as known in the art. Some computations for transforming the three-dimensional design produced by CAD computer 130 into images or bitmaps projected by or for use by projector 104 and movements of carriage 128 in the X and Z directions may be signaled or distributed between CAD computer 130 and processor 132.

[029] Projector 104 may project beams 112, 114 or other streams of energy (for clarity the beam envelope is designated 112 and directed beams for selective curing are designated 114 in Fig. 1A) under the control of processor 132, for selectively irradiating parts i.e. pre-defined areas, volumes or designated coordinates of upper surface 122S. Such beams may cure and harden and thus form the layers of material that make up model 120A and model 120B. The areas of upper surface 122S that are not irradiated and cured by beams 114 from projector 104, may be at least partially, or reversibly hardened, to achieve a hardened state by cooling or by some other method to form support 116.

[030] Material applicator system 180 is devised to spread thin layers of material 170 (e.g. 5-100 micron thick) on top of block 122 to form upper surface 122S. Certain properties of material 170 may include those described by one or more of the following characteristics: (a) material 170 melts at a first working temperature, e.g.  $>50^{\circ}\text{C}$ , so that it can be applied in a substantially liquid form for forming upper surface 122S; (2) it hardens when cooled to a second working temperature (e.g.  $20^{\circ}\text{C}$ - $50^{\circ}\text{C}$ ) which may for example be room temperature, at which temperature the uncured and unhardened material 170 in the uncured areas or regions of layer 122S may assume a hardened, e.g. solid state; and (3) it is curable by EM radiation provided by projector 104, to assume the required characteristics of model 120A and model 120B.

[031] Material reservoir 172 may store and supply material 170 to fluid material bath 152 via conduit 168. Other storage mediums for material 170 are possible such as for example a roll of material 170, storage as a powder or otherwise. Material 170 may be stored as a

paste, e.g. with viscosity >10,000 cps. In an embodiment, material 170 in material reservoir 172 may be heated to a first working temperature such that material 170 attains a liquid form, and then conduit 168 may pipe or move liquid material 170 to fluid material bath 152 via gravity or by using a pump, such as a peristaltic pump. In some embodiments, material 170 may be kept in material reservoir 172 in a powder or particulate form, and then conduit 168 may take a form of a tunnel or conveyor belt. In some embodiments, material 170 may be stored as a bar or block that may be partly immersed in fluid material bath 152 and is heated to liquid form there. Other supply and conveyance methods are possible. Supply of material 170 may maintain a substantially uniform amount of liquid material 170 in fluid material bath 152. Heater 148 may maintain a first working temperature e.g. >50°C, of the liquid material 170 in fluid material bath 152.

[032] A secondary roller 156 may include for example a cylinder partly immersed in fluid material bath 152 to collect a layer of liquid material 160 around secondary roller 156, and transfer it to primary roller 136 through contact between the two rollers 156 and 136, thereby providing a thin, uniform liquid material layer 140 around primary roller 136. When carriage 128 moves in an X direction, primary roller 136 may engage with upper surface 122S and apply a new layer of material 170 to block 122 through physical contact or other even application of material 170 to a top of block 122. Blower 164 may optionally provide a stream of air or chilled air in order to cool uncured areas of upper surface 122S.

[033] It will be noted that spreading even layers of liquid over a planar surface such as upper surface 122S through a roller arrangement as represented by primary roller 136 and secondary roller 156, are well known in the printing industry. Heat capacity of the outer surface of primary roller 136 may be kept low enough so that, on the one hand, material layer 140 does not harden on primary roller 136 and can be effectively applied as a liquid on top of printed block 122 to form the next upper surface 122S, and on the other hand, avoid excessive heating of the material or top surface of block 122 that could melt, distort or soften portions of a previously laid upper surface 122S.

[034] An arrangement of components of Fig. 1A may be replaced by an alternative arrangement wherein carriage 128 is stationary and material applicator system 180 is moving in the X and Z directions for similar effects and operation as described above. Combinations of relative movements of material applicator 180 and carriage 128 are possible.

[035] Reference is made to Fig. 1B, which depicts a side view of system 100 of Fig. 1A, wherein carriage 128 has moved in the X direction and slightly in the Z direction to engage primary roller 136 with the upper part of printed block 122 for forming upper surface 122S.

[036] Reference is made to Fig. 1C, which depicts a side view of system 100 of Fig. 1A where carriage 128 has further moved in the X direction so that the entire upper surface 122S has passed under blower 164 and where blower 164 may cool or otherwise alter a temperature of surface 122S to harden the uncured parts of the upper layer at surface 122S.

[037] An operational cycle, under the control of processor 132, for forming a single upper surface 122S on top of the previous upper surface, may include starting with the configuration of Fig. 1A, then moving carriage 128 in an X direction to reach a position of configuration of Fig. 1C. Carriage 128 may then move back to the configuration of Fig. 1A. During or following this cycle, carriage 128 is moved in the Z direction to accommodate a predefined layer thickness of upper surface 122S when moving in one direction, and to keep primary roller 136 away from upper surface 122S when moving in the other direction. Accordingly, during an operational cycle, application of a new layer of material may be made only when moving in one direction, preferably from the configuration of Fig. 1C to the configuration of Fig. 1A, which leaves the current layer added on top of upper surface 122S sufficiently wet for effective curing under the radiation coming from projector 104. When moving from the configuration of Fig. 1A to that of Fig. 1C, carriage 128 is preferably moved slightly in the Z direction to disengage primary roller 136 from upper surface 122S. Blower 164 may work continuously in both directions, as needed to cool upper surface 122S so that it hardens toward adding the next layer during moving from the configuration of Fig. 1C to that of Fig. 1A.

[038] Depending on the chemical and physical properties of material 170, the previously added layer may be sufficiently cured and hardened to allow primary roller 136 to engage with upper surface 122S in any or both directions. Also, the ambient temperature within printer 100 may be cold enough to harden the last printed layer with partial operation, or even without the operation, of blower 164.

[039] It will be also noted that a single printing material 170 may be used for providing both the support functionality of support 116 and the model functionality for building model 120A and model 120B, where the build material is cured, hardened to a solid state by irradiation from projector 104 while the support 116 remains uncured and is reversibly

hardened merely by cooling. The support areas 116 of block 122 which remain uncured by selective curing and are reversibly hardened by exposure to cooling air may easily be removed after construction of the object is complete, e.g. by exposure to heat or mechanical means known in the art.

[040] Reference is made to Figs. 2A and 2B, schematic side and top views, respectively, of an object being constructed layer by layer, where the object is surrounded and supported by supporting material, in accordance with an embodiment of the invention. In Figs. 2A-2B, primary roller 136 of Fig. 1A has applied material over the entire area of tray 124, and the selective irradiation by projector 104 distinguishes between areas of layer 122S wherein is found model 120A and 120B from areas that are to remain as support 116A. It will be noted that a substantial amount of supporting material may be wasted in this configuration.

[041] Reference is made to Figs. 3A and 3B, schematic side and top views, respectively, of objects being constructed layer by layer, where the objects are surrounded and supported by a reduced volume of supporting material, in accordance with an embodiment of the invention. In Figs. 3A and 3B, an area of support 116B has been reduced in size, thus reducing the waste of the supporting material 116B. In such a configuration, processor 132 may control a motion of carriage 128 in the X and Z directions, so that primary roller 136 is raised (or carriage 128 is lowered), initially relative to tray 124, and later relative to upper surface 122S, so that material for support 116 is not applied outside the rectangle defined by support 116B in Figs. 3A-3B.

[042] It will be noted that, in some embodiments, it can be the material applicator system 180 of Fig. 1A which is moved under the control of processor 132, while carriage 128 remains stationary.

[043] Reference is made to Figs 4A and 4B, side and top views of objects on an elevated pad being constructed layer by layer, in accordance with an embodiment of the invention. To avoid excessive application of supporting material, Figs. 4A though 7B depict the use of pads, that are placed on tray 124 towards commencement of an object fabrication session in order to reduce the amount of supporting material waste. For descriptive purposes, the 'footprint' of a model 120A may be said to extend over the area on tray 124 that will be shaded by the finished model when illuminated by an imaginary light source placed at a zenith above the object. Such footprint may be calculated from the digital representation of model 120A, based on common knowledge in the art of computer aided design. The support

structure 116 that is needed for supporting the layer by layer building process of a given model may be substantially congruent to the volume above the model's footprint.

[044] It will also be noted that when primary roller 136 applies a material layer 140 as upper surface 122S, the actual material deposition may be limited to the area of the size and shape of the previous upper surface 122S. Accordingly, a typical structure (that includes both the model 120A and support 116) built by system 100 is made up of substantially similarly dimensioned layers whose shape is determined when the first layers are printed, and thereby define the actual contact surface(s) of block 122 with primary roller 136. Some fluctuations, with the effect of gradually enlarging the layer areas by some spill-over of printed material, are possible, but such fluctuations may add small amounts of support 116 material, while the accuracy of the model 120A and top surface layer 122S, as determined by the shape selectively irradiated by projector 104 for each layer, remains largely intact.

[045] Placing one or more elevation pads 200A on the tray 124 prior to printing a first layer, may determine the printing pattern that will be carried over to layers applied above the pad. A pad 200A may be or include a thin, flatly shaped object that encompasses the footprint of a model to be built. It may be attachable to tray 124, and easily detachable from tray 124 and the final built object 120 upon construction completion. In some embodiments, pad 200A may be formed of a magnetic sticker attached to a metal/iron tray 124. Other removable stickers, even paper made, may provide the desired functionality. Preparation and placement of such pads 200A in a preparatory stage is described in Fig. 8 below. It will be noted that optionally, when printer 100 is used for repetitively producing batches of identical or similar models, and where a finished model may be easily detached from its pad 200A, the pad 200A may remain attached to tray 124, ready for a next fabrication process.

[046] In Fig. 4A, pad 200A has been placed on the tray 124 and defines a shape and area of subsequent layers. Pad 200A therefore defines the footprints of both model 120A and model 120B. It will be noticed that in the example of Fig. 4B, pad 200A is both shorter and narrower than tray 124, and therefore the use of pad 200A may save substantial amounts of supporting material for support 116E.

[047] Reference is made to Figs. 5A and 5B, schematic side and top views of a set of objects, each on a separate elevated pad, being constructed layer by layer with a reduced volume of supporting material, in accordance with an embodiment of the invention. Fig. 5A describes model 120A and model 120B of Fig. 4A, but with two separate pads 200B for

model 120A and support structure 116F and pad 200C for model 120B and support structure 116G. Figs. 5A-5B demonstrate a waste of support 116G along the sides of the block containing model 120B, as may be anticipated when pad 200C is slightly larger, i.e. broader than necessary for erecting a support structure 116G.

[048] Reference is made to Figs. 6A and 6B, schematic side and top views of a set of objects, on separate elevated pads, being constructed layer by layer, where the shape of each pad approximates an outline of the object being constructed, in accordance with an embodiment of the invention. In Figs. 6A and 6B, pads 200B and pad 200D have been cut, shaped and placed according to the footprints of model 120C and model 120B, respectively. However, model 120C is lower than model 120B, and support 116H includes a wasted surplus amount of supporting material above model 120C.

[049] Reference is made to Figs. 7A and 7B, schematic side and top views of a set of objects on separate elevated pads, being constructed layer by layer, where layer by layer construction of one of the objects has ceased at a lower elevation than a construction of the other object, in accordance with an embodiment of the invention. In Figs. 7A and 7B, similar pads may be used for the two models but support 116K avoids the surplus support layers on top of model 120C by processor 132 of Fig 1A by limiting a number of passes of primary roller 136 above model 120C once an upper layer of model 120C has been completed. The final layers of block 120 are added only for building and supporting model 120B. An elevator or actuator may control primary roller 136 to coordinate contact of a top layer of block 120 with roller 136.

[050] In some embodiments, material 170 of Fig. 1 may be characterized by the following properties: (a) it is sufficiently hard at the working temperature of printer 100 to serve as an effective support 116 throughout the building process of printed block 122. An exemplary working temperature is between 20-50°C; (b) it melts when heated (at >50°C), to provide a liquid whose viscosity (e.g. 100-5000 cps) and adhesiveness are sufficient for forming an even liquid material layer 140 over primary roller 136 through material layer 160 over secondary roller 156 collected from fluid material bath 152 in container 144 heated by heater 148, (c) it is curable by beams 112, i.e. directed beams 114, from projector 104, under the control of processor 132, to enable selective curing by beams 114A and 114B of the areas of the upper layer 122S which are to form models 120A and 120B, respectively, and distinguish between the model(s), and the support structure 116 areas under the control of

processor 132. Support 116 may be removed from finished printed block 122 by a chemical and/or physical process, such as dissolving or melting, that does not affect the cured models 120A and 120B.

[051] Exemplary printing materials usable with printer 100 of Fig. 1A are prescribed in the following tables:

**Table 1: Examples of Characteristic Formulation of a Printing Material**

#	Trade Name	Chemical Type	Function in the formulation	Supplier
A	Photomer-6010	Urethane Acrylate Oligomer	Oligomer	Cognis
B	SR-339	Phenoxy ethyl Acrylate	monomer	Sartomer
C	SR -351	Trimethylol propane triacrylate	Cross-linker	Sartomer
D	Irgacure 907	alpha-Amino Ketone	Free radical photo-initiator	Ciba Specialties Chemical Inc.
E	BP	Benzophenone	Free radical photo-initiator	Satomer
F	Triethanol Amine	Ternary Amine	Free radical Cointiator	Sigma
G	Byk 307	Silicone Surface Additive	Surface agent	Byk Chemie
H	MEHQ	4-Methoxy phenol	Inhibitor	Sigma
I	Cyracure UVR-6110	3,4 Epoxycyclohexylmethyl-3,4-epoxycyclohexylcarboxylate	Epoxy oligomer	Union Carbide
J	UVI-6974	Mixed Triarylsulfonium Hexafluoroantimonate Salts	Cationic photo-initiator	Union Carbide
K	CHVE	1,4-cyclohexane dimethanol divinyl ether	Vinyl Ether Monomer	ISP

L	UV TITAN M160 VEG	Organic Treated Titanium Dioxide	White pigment	KEMIRA PIGMENT S
M	Disperbyk 110	Copolymer with acidic groups	Pigment Dispersant	Byk Chemie
N	Spectrasol RED BLG	Solvent Red 127	Dye	Spectra Colors Corp.
O	Tint Aid PC 9703	Organic pigment	Organic pigment	Elementis Specialties
P	Disperbyk 163	High molecular weight block copolymer with pigment affinic groups	Pigment Dispersant	Byk Chemie
Q	V-Cap	Vinylcaprolactam	Monomer	ISP
R	V-Pyrol	Vinylpyrrolidone	Monomer	ISP
S	Silicon acrylated oligomer	Ebecryl 350	Phase separation promoter	UCB Chemicals
T	Trimethylol propane tri(3- mercaptopro pionate)	Sulfur-containing compound	Crosslinker	BRUNO BOCK Chemische Fabrik HMBH & CO.
Z	Myristic acid	Fatty acid	Wax to harden formulation	KIC chemicals, inc.

**Table 2: Examples of Possible Formulation Compositions of the Printing Material**

Example	A	B	C	D	E	F	G	H	I	J	K	Q	R	S	T	Z
1	X	X	X	X			X	X								
2	X	X		X			X	X								
3	X		X	X			X	X								
4		X	X	X			X	X								

5	X	X	X		X	X	X	X							
6	X	X			X	X	X	X							
7	X		X		X	X	X	X							
8		X	X		X	X	X	X							
9	X		X	X			X	X			X				
10	X		X		X	X	X	X			X				
11							X	X	X	X	X				
12		X	X	X			X	X	X	X					
13	X	X	X	X	X	X	X	X	X	X	X				X
14	X	X	X	X			X	X				X			
15	X	X	X	X			X	X					X		X
16	X	X	X	X			X					X		X	
17	X	X	X	X			X					X			X

[052] An exemplary melting point for formulation with Z (Myristic acid) is 54°C.

[053] Reference is made to Fig. 8, a flow diagram of a method in accordance with an embodiment of the invention. In some embodiments a method for printing one or more models layer by layer may include e.g. in block 901, determining a shape, size and placement position of one or more pads upon which a printing of objects is to be undertaken. In some embodiments, a processor or CAD computer may calculate a footprint of the model to be constructed and further determine a shape and placement of the pad to correspond to the model. A standard size and shape of pad may also be used. In block 903, one or more pads may be cut to fit a footprint of a model to be printed. A processor or some other computer may provide directions for cutting the pads whose shapes have been determined in block 901. As an illustration, the pads may be formed of a thin magnetic substrate, and in block 903 an apparatus may print the pad shapes on pages made of the magnetic substrate for manual cutting, or use a plotter to move a cutting blade for cutting the pads automatically. In block 905, the fitted pads may be placed on a printing tray. In some embodiments, the actions of blocks 901-905 may be eliminated, and in some embodiments, a single placement of pads may suffice for several printing sessions, such as for batches of models that have similar footprints. In such cases, finished printed structures may be detached from the pads, leaving the pads properly attached for printing a next batch.

[054] In block 907, a layer counter may be set to 1. In block 909, a printing carriage may be positioned vertically on a Z axis for the current layer to be applied. In block 911, a first layer of material may be applied. In block 913, a bit map may be obtained for a current layer. In block 915, an image may be projected from a bit map of the current layer and the material may be selectively cured according to the bit map. In block 917, the current layer may be allowed to cool or be cooled such that the uncured portion of the layer is hardened. Such cooling may be accomplished by waiting sufficient time for cooling under the atmosphere of printer, and/or with the assistance of a blower passing above the surface. In block 919 and 921 a determination may be made as to whether a current layer is a last layer to be printed. In step 921, if the current layer is not the last layer, the layer number may be incremented. In block 923, if the current layer is the last layer, then the printing may be terminated.

[055] Reference is made to Fig. 9, a flow diagram of a method in accordance with an embodiment of the invention. Embodiments of the invention may include a method for construction of an object, layer by layer, where the method may include in block 948 applying a first layer of a material in liquid form to a fabrication tray or surface upon which an object is to be built layer by layer, where said liquid material is cooled to a hardened state to provide a layer. Said first layer may provide a release layer between the object to be printed and the fabrication tray. A method may continue to block 950, where a layer of a material in a liquid state is applied on top of the previous layer. Continuing to block 952 the layer of liquid material applied in block 950 is selectively cured only at pre-defined points, coordinates or areas of the layer, where such pre-defined area corresponds to a location of the object to be printed in the layer. Areas in the layer that are not included in the pre-defined area and that surround the cured areas may be left uncured. In block 954, the surrounding areas that are uncured may cool or be cooled to a hardened state, able to support the cured pre-defined areas as well as subsequent upper layers of the block, when a remainder of the layers are deposited. In block 956, the surrounding support material i.e. supporting material may be removed.

[056] While the invention has been described with respect to a limited number of embodiments, it will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and described herein. Rather the scope of the present invention includes both combinations and sub-combinations of the various

features described herein, as well as variations and modifications which would occur to persons skilled in the art upon reading the specification and which are not in the prior art.

## CLAIMS

What is claimed is:

1. A method for printing a three-dimensional object on a tray, layer-by-layer, the method comprising:
  - a. receiving three-dimensional CAD data of an object to be built;
  - b. processing the three-dimensional CAD data to receive slice data representative of cross-sectional layers of the object;
  - c. delivering heated photocurable material to a surface above said tray to form a layer of material on said surface above said tray, said material having at least the following properties:
    - being liquid when heated and delivered to said surface at a working temperature,
    - being solidifiable by exposure to a source of curing radiation, and
    - being solidifiable when cooled to a temperature less than said working temperature;
  - d. projecting from a source of radiation to said layer, an image representative of said slice data representative of a cross-section of said layer, to selectively illuminate pixels of said cross-section thereby curing the material within said cross-section;
  - e. cooling said layer to a temperature less than said working temperature to harden the uncured material;
  - f. repeating steps c-e until the three-dimensional object made up of said cured material surrounded at least partly by hardened material is completed; and
  - g. removing said hardened material.
2. The method of claim 1, wherein said photocurable material comprises a combination of photopolymer and wax.
3. The method of claim 1, wherein said removing includes melting said hardened material by heating.
4. The method of claim 1, wherein said removing includes dissolving said hardened material using a solvent.

5. The method of claim 4, wherein said solvent is selected from the group consisting of heated oil and heated water-based solution.
6. The method of claim 1, wherein said heated photocurable material is delivered to said surface by a revolving roller covered by a layer of said heated photocurable material.
7. The method of claim 6, further comprising placing on said tray a heightened pad said pad being smaller than the tray, shaped and positioned prior to delivery of said heated photocurable material according to a footprint of said object, thereby limiting delivery of said material by said roller to surfaces above said heightened pad.
8. The method of claim 7, wherein said heightened pad comprises at least two distinct pads where said object consists of at least two separate objects.
9. The method of claim 8, wherein said at least two separate objects include a first object and a second object, said first object being higher than said second object, and the method of repeating steps c-e for printing said first object and said second object is repeated until said second object is completed, whereafter said roller only contacts said first object and steps c-e are repeated until said first object is completed, without adding layers above said second object.
10. A system for layer by layer fabrication of an object comprising:
  - a processor for receiving three-dimensional CAD data of an object to be built and processing said three-dimensional CAD data to receive slice data representative of cross-sectional layers of said object;
  - a fabrication tray upon which said object is to be fabricated;
  - an applicator for delivering heated photocurable material to said fabrication tray, said material in a liquid state during said application, to form a layer of liquid material; and
  - a source of radiation to selectively cure a cross-section of said layer according to said slice data, and to leave uncured the material in a remaining area of said layer;
  - a blower or cooling unit to cool said uncured remaining area to harden the uncured material to support said cured material in said layer and in subsequent layers; and

a source of heat for removing said hardened material upon completion of fabrication of the object.

11. The system as in claim 10, wherein said applicator comprises a roller, said roller to deliver said material to an upper surface over said fabrication tray.
12. The system as in claim 10, comprising a heightened pad on said fabrication tray upon which is to be deposited said heated photocurable material, said pad shaped according to a footprint of said object and having total dimensions smaller than said tray
13. The system as in claim 10, comprising an elevator to raise a level of said applicator to engage a top surface on said elevated pad.
14. A method of printing an object layer by layer, comprising:  
  
applying a layer of a material in a liquid state to a platform upon which is to be printed said object layer by layer;  
  
selectively curing a pre-defined area of said layer, said pre-defined area corresponding to a location of said object in said layer, while leaving uncured an area of said layer surrounding said pre-defined area; and  
  
cooling said area of said material of said layer surrounding said pre-defined area to a hardened state, said material of said area surrounding said pre-defined area thereby supporting said cured pre-defined area.
15. The method as in claim 14, wherein said cooling comprises blowing air at said layer.
16. The method as in claim 14, wherein said applying comprises bringing a roller into contact with said layer, said roller bearing said material.
17. The method as in claim 16, comprising heating said material prior to said roller applying said material.
18. The method as in claim 14, comprising removing uncured material upon a completion of printing said object.

19. The method as in claim 14, wherein said applying comprises applying said material to an elevated pad on said platform.
20. The method as in claim 19, wherein said applying comprises applying said material only to a surface over said elevated pad.
21. The method as in claim 19, comprising shaping said pad to conform to a footprint of said object.
22. The method as in claim 21, wherein said shaping comprises applying a dimension of said footprint to said pad.
23. A device comprising a pad, said pad to elevate an area of a printing surface for layer by layer printing of an object, wherein said elevated area is above said printing surface, and wherein a contact of an applicator of a printing material is limited to said elevated area.
24. The device as in claim 23, wherein a shape of said elevated area corresponds to a footprint of said object.

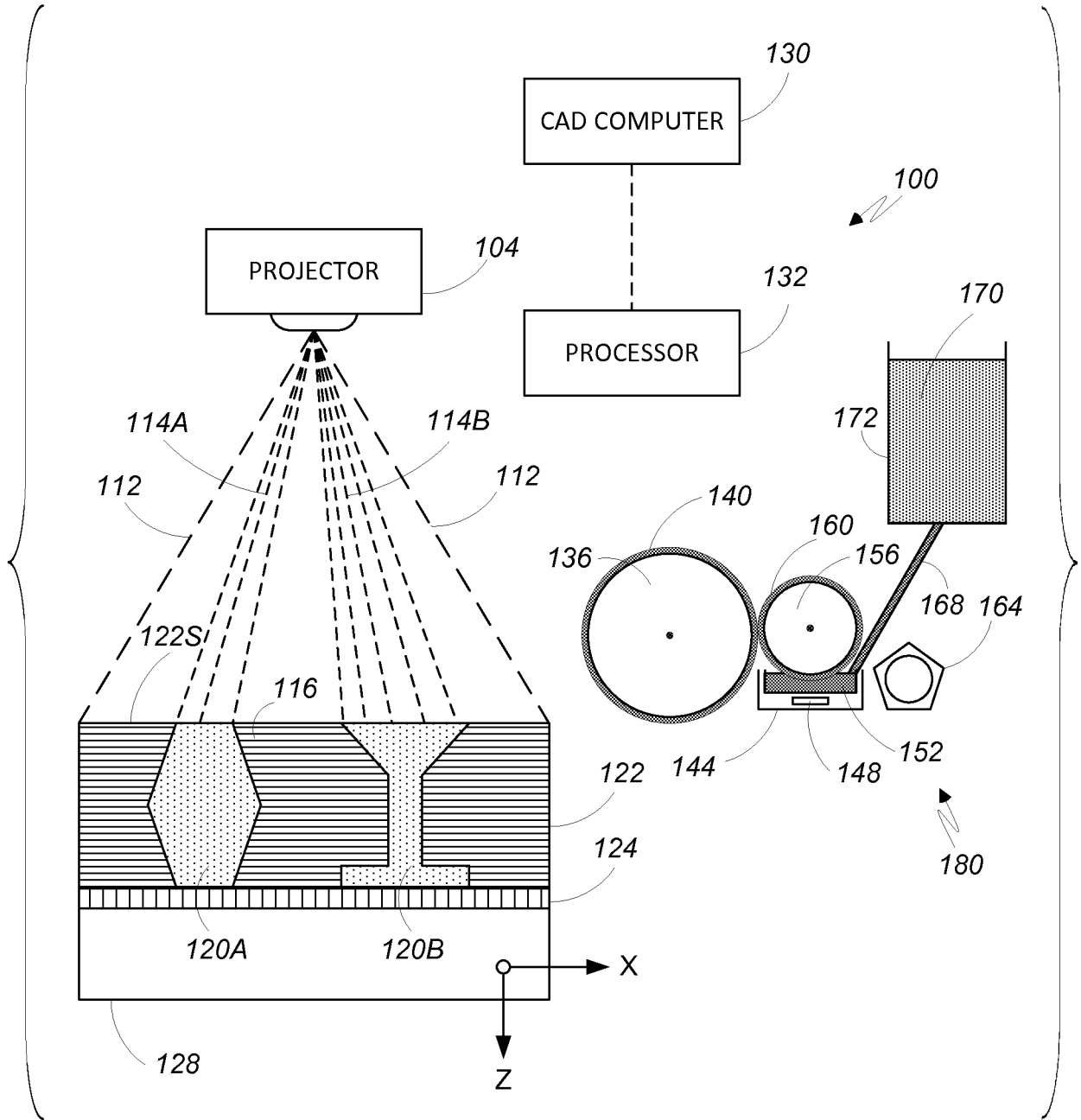
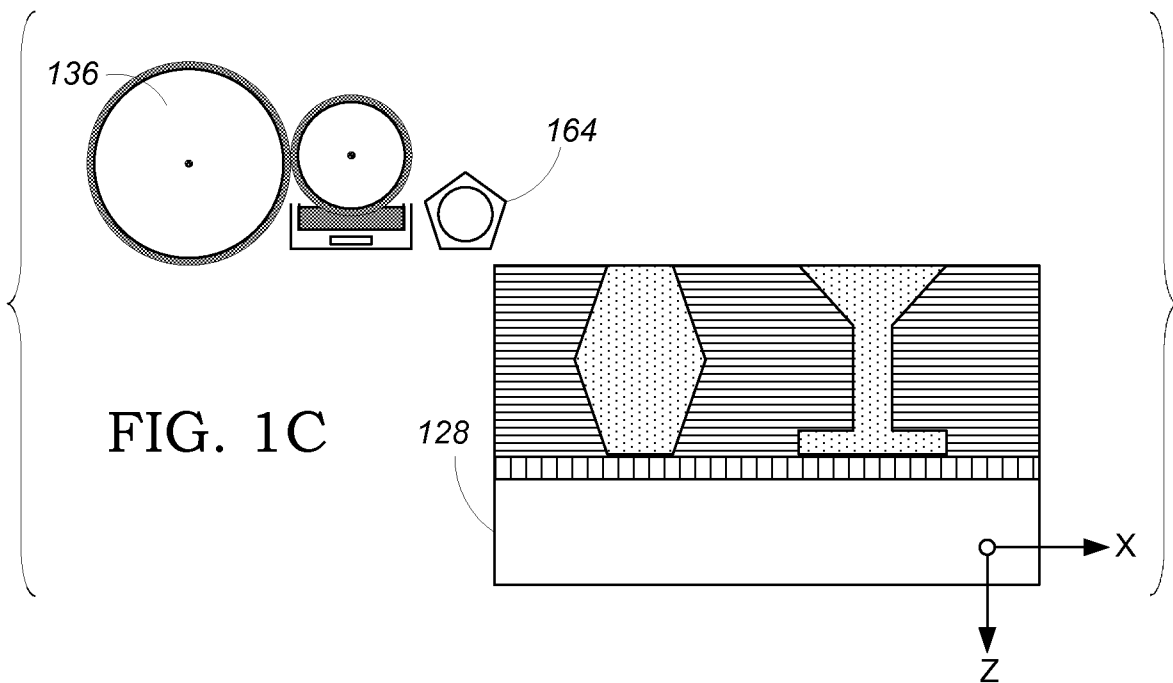
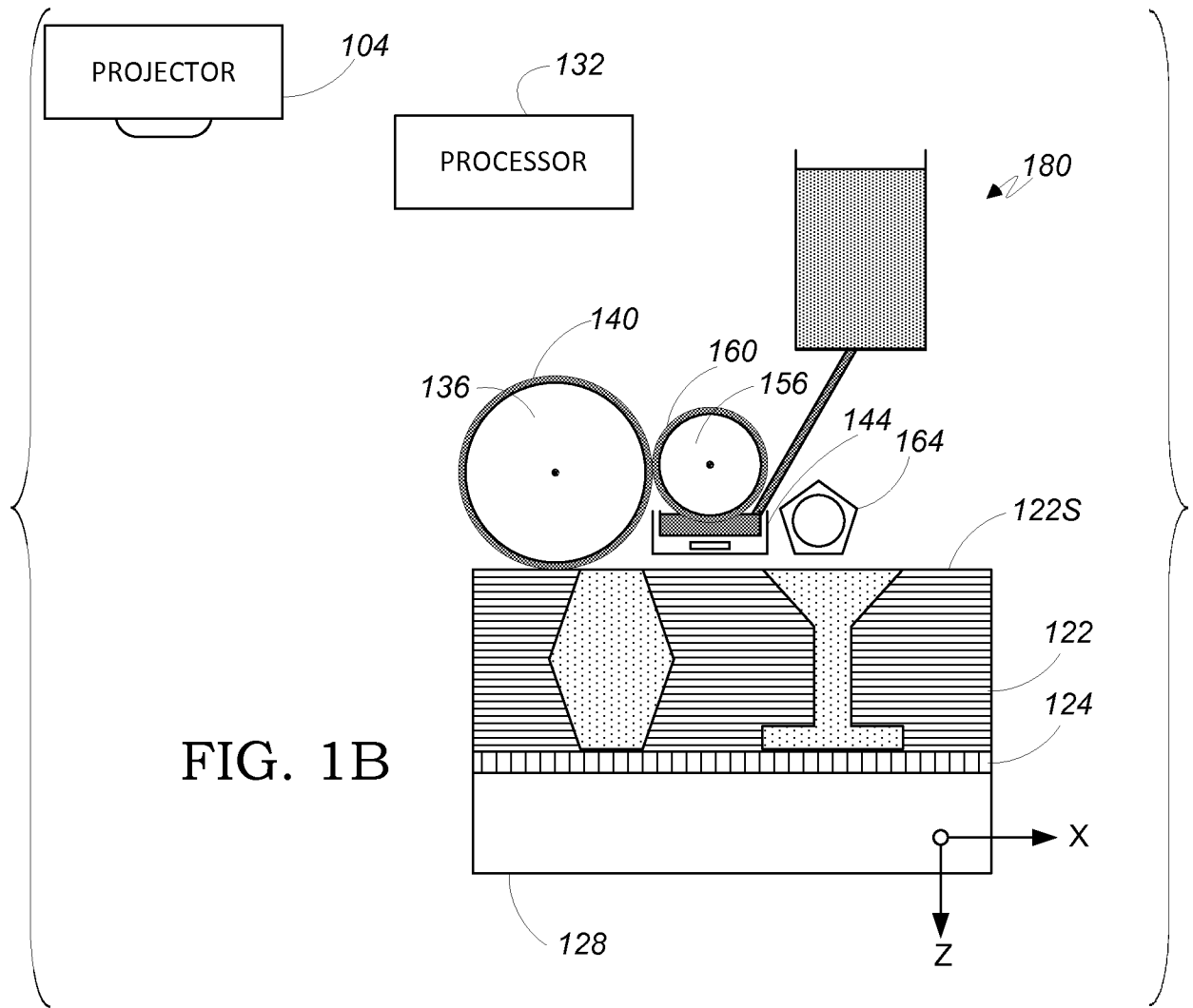
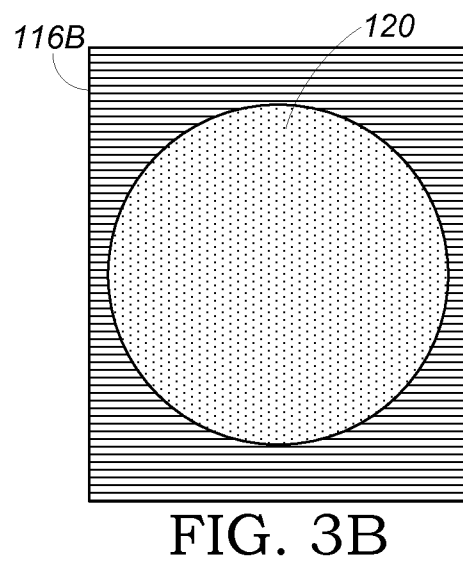
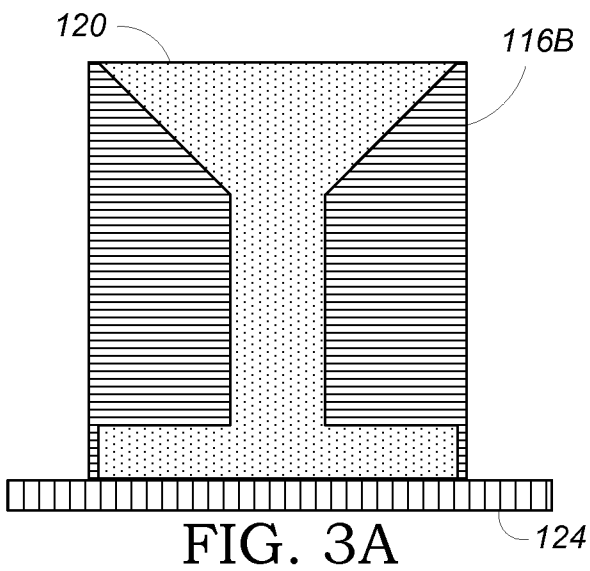
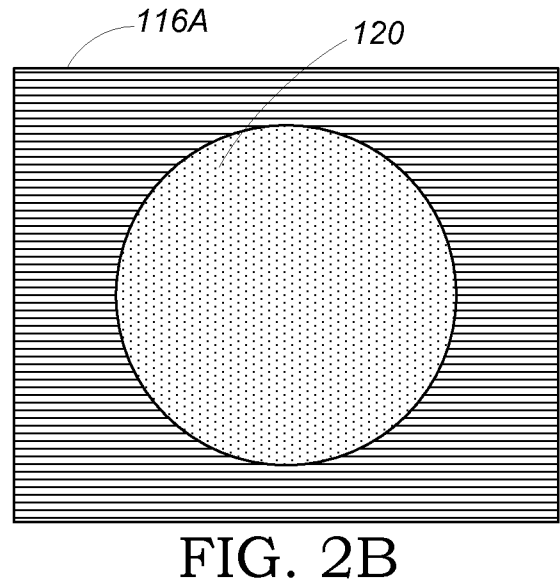
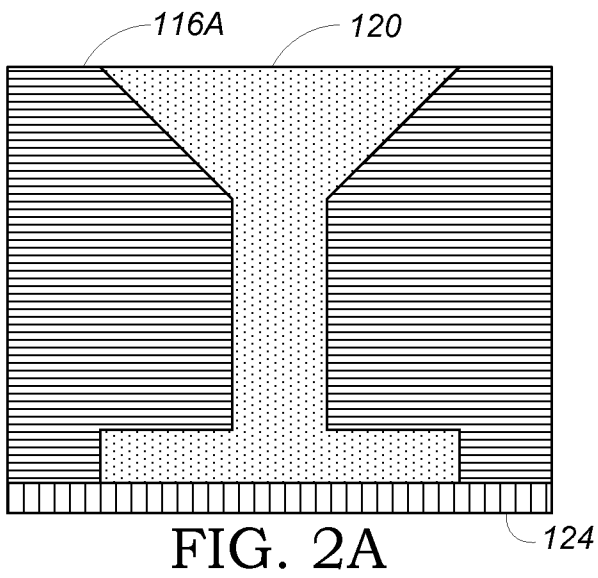


FIG. 1A





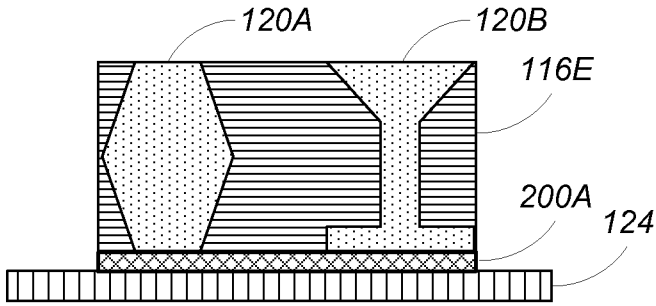


FIG. 4A

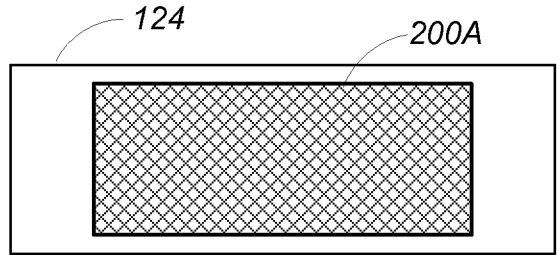


FIG. 4B

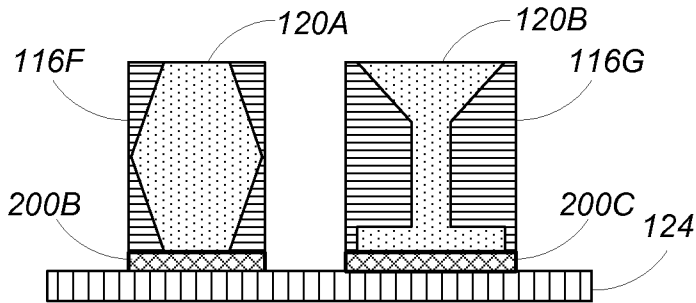


FIG. 5A

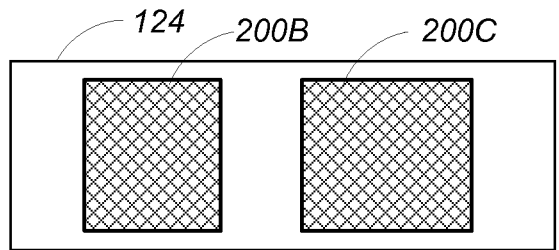


FIG. 5B

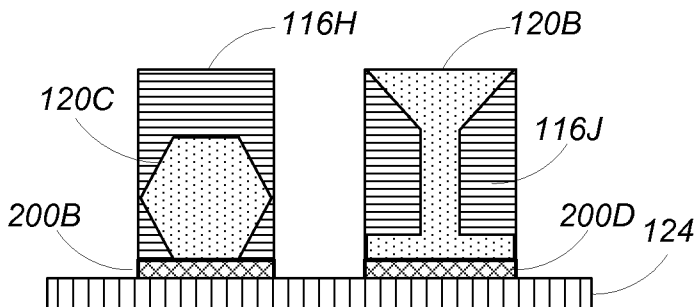


FIG. 6A

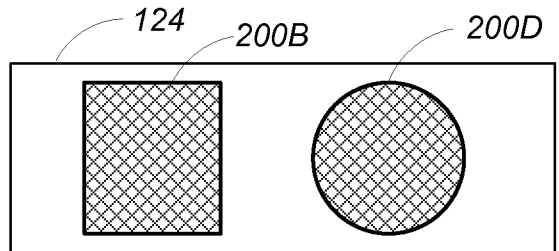


FIG. 6B

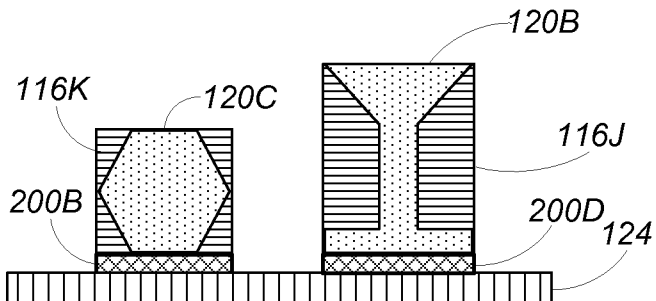


FIG. 7A

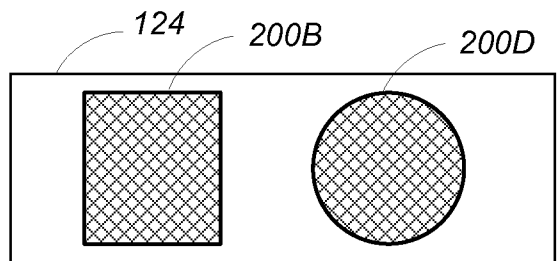


FIG. 7B

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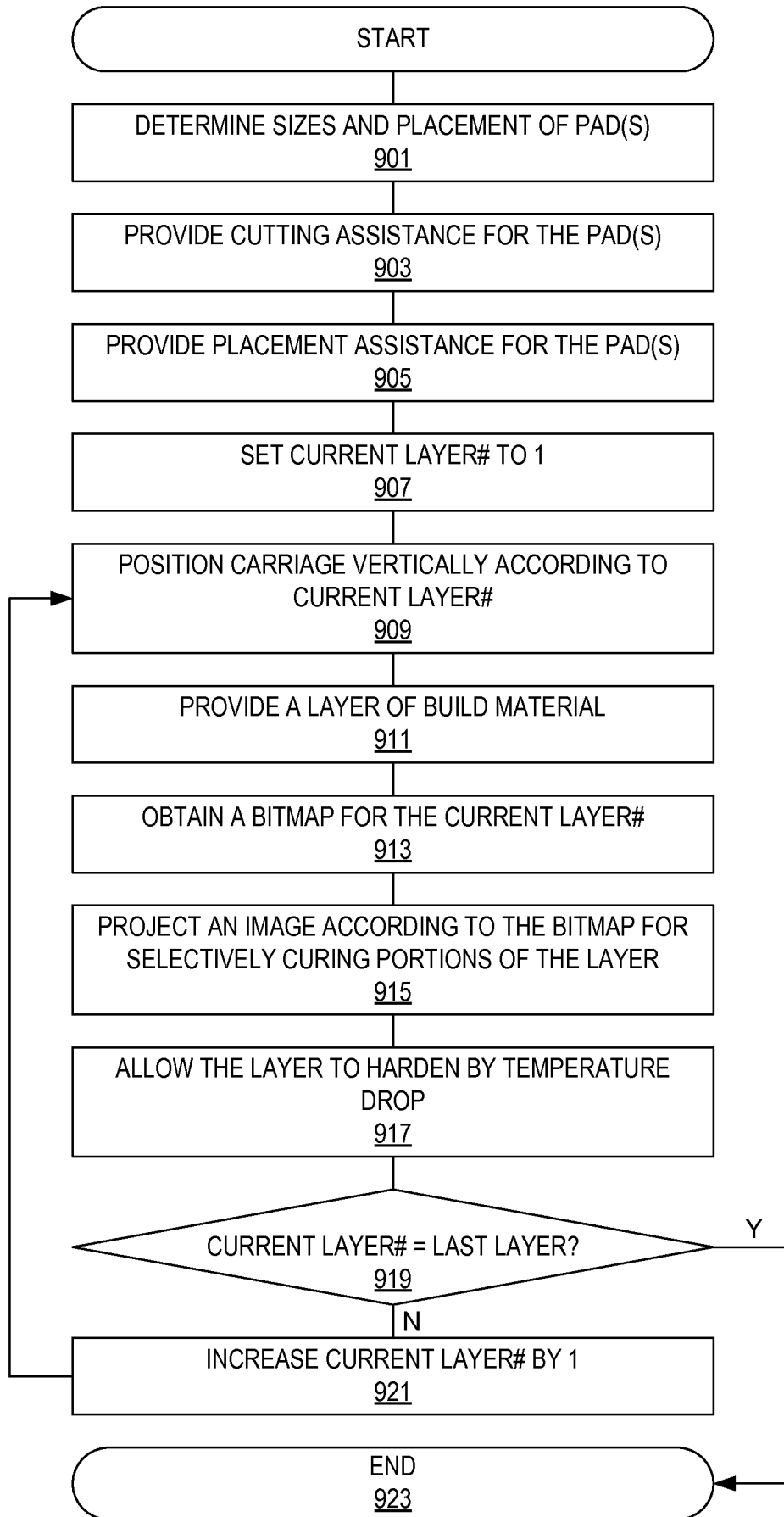


FIG. 8

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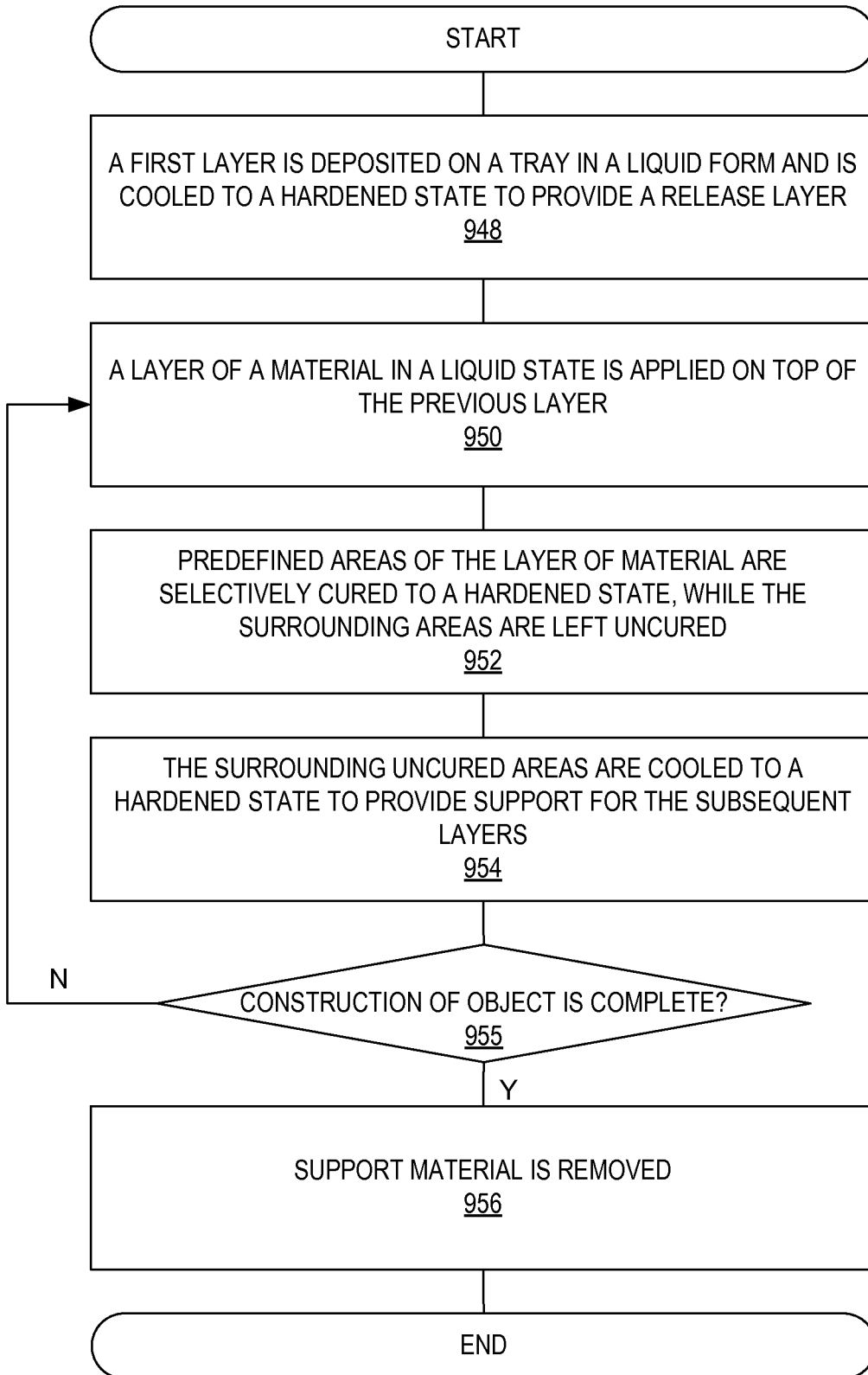


FIG. 9