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System for improving safety in three-dimensional printing

Abstract

A safety system, for a rotary tray of a three-dimensional printing system comprises a latch having a lock member and being operable to assume a locked state in which the latch prevents the door of the printing system from closing while the lock member prevents the tray from rotating, and an unlocked state in which the latch allows the door to close while the lock member allows the tray to rotate.

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Background/Summary

RELATED APPLICATIONS (1) This application is a National Phase of PCT Patent Application No. PCT/IL2021/050488 having International filing date of Apr. 27, 2021, which claims the benefit of priority under 35 USC § 119(e) of U.S. Provisional Patent Application No. 63/015,699 filed on Apr. 27, 2020. The contents of the above applications are all incorporated by reference as if fully set forth herein in their entirety.

FIELD AND BACKGROUND OF THE INVENTION
(1) The present invention, in some embodiments thereof, relates to three-dimensional printing and, more particularly, but not exclusively, to a system for improving safety in three-dimensional printing.
(2) Additive manufacturing (AM) is generally a process in which a three-dimensional (3D) object is manufactured utilizing a computer model of the object. Such a process is used in various fields, such as design related fields for purposes of visualization, demonstration and mechanical prototyping, as well as for rapid manufacturing.
(3) The basic operation of any additive manufacturing system consists of slicing a three-

dimensional computer model into thin cross sections, translating the result into two-dimensional position data and feeding the data to control equipment which manufactures a three-dimensional structure in a layerwise manner.

(4) Additive manufacturing entails many different approaches to the method of fabrication, including three-dimensional printing, e.g., three-dimensional inkjet printing, laminated object manufacturing, fused deposition modeling and others.

(5) In three-dimensional printing processes, for example, a building material is dispensed from a dispensing head having a set of nozzles to deposit layers of building material on a supporting structure. Depending on the building material, the layers may then be cured or solidified using a suitable device. The building material may include modeling material, which forms the object, and support material, which supports the object as it is being built. Various three-dimensional printing techniques exist and are disclosed in, e.g., U.S. Pat. Nos. 6,259,962, 6,569,373, 6,658,314, 6,850,334, 7,183,335, 7,209,797, 7,225,045, 7,300,619, 7,364,686, 7,500,846, 7,658,976, 7,962,237, 9,031,680, and 10,611,136, U.S. Published Application No. US 20130040091, all of the same Assignee, the contents of which are hereby incorporated by reference.

(6) For example, U.S. Pat. No. 10,611,136 discloses a three-dimensional printing system with a rotary tray configured to rotate about a vertical axis, a printing head having a plurality of separated nozzles, and a controller configured for controlling the inkjet printing heads to dispense, during the rotation, droplets of building material in layers. The system also includes a leveling device that straightens the newly formed layer prior to the formation of successive layer thereon.

SUMMARY OF THE INVENTION

(7) According to an aspect of some embodiments of the present invention there is provided a safety system, suitable for a rotary tray of a three-dimensional printing system, which comprises a printing head, a controller, and a printing chamber with an access opening. The safety system comprises a latch having a lock member and being operable to assume a locked state in which the latch prevents the door from closing while the lock member prevents the tray from rotating, and an unlocked state in which the latch allows the door to close while the lock member allows the tray to rotate. The safety system optionally and preferably comprises a door state sensor, configured for transmitting to the controller a signal indicative whether a door at the access opening is open or closed.

(8) According to some embodiments of the invention the invention the safety system comprises a sprocket wheel connected to the tray to rotate therewith, wherein the lock member engages the sprocket wheel in the locked state, and disengages from the sprocket wheel in the unlocked state.

(9) According to some embodiments of the invention the latch is operable to reciprocally slide radially with respect to the tray, wherein when the latch is extracted outwardly the latch assumes the locked state, and when the latch is retracted inwardly the latch assumes the unlocked state.

(10) According to some embodiments of the invention the latch protrudes out of the access opening when extracted outwardly, thereby preventing the door from closing.

(11) According to some embodiments of the invention the safety system comprises a spring constituted to bias the latch to maintain the locked state upon activation of the latch.

(12) According to some embodiments of the invention safety system comprises an elastic lever connected to the latch in a manner that when the lever is in a relaxed state, the lever collides with a stopper element and prevents the latch from assuming the unlocked state, and when the lever is in a strained state the lever bypasses the stopper element allowing the latch to assume the unlocked state.

(13) According to some embodiments of the invention a height of the lock member is selected to support the tray in the locked state. According to some embodiments of the invention a height of the lock member is selected to support the tray in the locked state but not in the unlocked state.

(14) According to some embodiments of the invention the latch is a push-push latch.

(15) According to an aspect of some embodiments of the present invention there is provided a

three-dimensional printing system, comprising a printing head, a rotary tray, a controller, a printing chamber with an access opening, and the safety system as delineated above and optionally and preferably as further detailed below.
(16) According to an aspect of some embodiments of the present invention there is provided a method of printing a three-dimensional object. The method comprises: receiving three-dimensional printing data corresponding to the shape of the object, feeding the data to the three-dimensional printing system, operating the three-dimensional printing system to print the object, opening the door of the printing chamber, activating the latch to lock the tray, and removing the object from the tray.
(17) According to an aspect of some embodiments of the present invention there is provided a system for three-dimensional printing. The system comprises a rotary tray configured to rotate horizontally about a vertical axis, a printing head configured for dispensing a building material, a leveling device for straightening building material dispensed by the printing head, a supporting roller, positioned under the tray below the leveling device, for absorbing a force applied by the leveling device, and a controller configured for controlling the printing head to print a three-dimensional object on the tray;
(18) According to some embodiments of the invention the three-dimensional printing system comprises a latch, having a lock member and being operable to assume a locked state in which the lock member prevents the tray from rotating, and an unlocked state in which the lock member allows the tray to rotate.
(19) According to some embodiments of the invention a height and shape of the lock member is selected to at least partially absorb vertical forces exerted on the tray.
(20) According to some embodiments of the invention the latch is a push-push latch.
(21) According to some embodiments of the invention the latch comprises a lever and a stopper element.
(22) According to some embodiments of the invention the lever comprises a metal sheet and the stopper element comprises a screw head.
(23) Unless otherwise defined, all technical and/or scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the invention pertains. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of embodiments of the invention, exemplary methods and/or materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and are not intended to be necessarily limiting.
(24) Implementation of the method and/or system of embodiments of the invention can involve performing or completing selected tasks manually, automatically, or a combination thereof. Moreover, according to actual instrumentation and equipment of embodiments of the method and/or system of the invention, several selected tasks could be implemented by hardware, by software or by firmware or by a combination thereof using an operating system.
(25) For example, hardware for performing selected tasks according to embodiments of the invention could be implemented as a chip or a circuit. As software, selected tasks according to embodiments of the invention could be implemented as a plurality of software instructions being executed by a computer using any suitable operating system. In an exemplary embodiment of the invention, one or more tasks according to exemplary embodiments of method and/or system as described herein are performed by a data processor, such as a computing platform for executing a plurality of instructions. Optionally, the data processor includes a volatile memory for storing instructions and/or data and/or a non-volatile storage, for example, a magnetic hard-disk and/or removable media, for storing instructions and/or data. Optionally, a network connection is provided as well. A display and/or a user input device such as a keyboard or mouse are optionally provided as well.

Description

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

(1) Some embodiments of the invention are herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of embodiments of the invention. In this regard, the description taken with the drawings makes apparent to those skilled in the art how embodiments of the invention may be practiced.

(2) In the drawings:

(3) FIGS. **1**A-C are schematic illustrations of an additive manufacturing system according to some embodiments of the invention;

(4) FIGS. **2**A-**2**C are schematic illustrations of printing heads according to some embodiments of the present invention;

(5) FIGS. **3**A and **3**B are schematic illustrations demonstrating coordinate transformations according to some embodiments of the present invention;

(6) FIGS. **4**A-**4**D are schematic illustrations showing a top view (FIGS. **4**A and **4**B) and a side view (FIGS. **4**C and **4**D) of a printing chamber, a rotary tray, and a latch, according to some embodiments of the present invention;

(7) FIGS. **5**A-C are schematic illustrations showing perspective views of a latch for locking and unlocking a rotary tray according to some embodiments of the present invention;

(8) FIG. **6**A-C are schematic illustrations showing a perspective bottom view (FIG. **6**A) and side views (FIGS. **6**B and **6**C) of a latch for locking and unlocking a rotary tray according to some embodiments of the present invention;

(9) FIG. **7** is a schematic illustration showing an exploded view of a platter on a vertical axis, according to some embodiments of the present invention; and

(10) FIGS. **8**A and **8**B are schematic illustrations showing a lock member that supports a platter, according to some embodiments of the present invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS OF THE INVENTION

(11) The present invention, in some embodiments thereof, relates to three-dimensional printing and, more particularly, but not exclusively, to a system for improving safety in three-dimensional printing.

(12) Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not necessarily limited in its application to the details of construction and the arrangement of the components and/or methods set forth in the following description and/or illustrated in the drawings and/or the Examples. The invention is capable of other embodiments or of being practiced or carried out in various ways.

(13) The method and system of the present embodiments manufacture three-dimensional objects based on computer object data in a layerwise manner by forming a plurality of layers in a configured pattern corresponding to the shape of the objects. The computer object data can be in any known format, including, without limitation, a Standard Tessellation Language (STL) or a StereoLithography Contour (SLC) format, Virtual Reality Modeling Language (VRML), Additive Manufacturing File (AMF) format, Drawing Exchange Format (DXF), Polygon File Format (PLY) or any other format suitable for Computer-Aided Design (CAD).

(14) The term “object” as used herein refers to a whole object or a part thereof.

(15) Each layer is formed by an additive manufacturing apparatus which scans a two-dimensional surface and patterns it. While scanning, the apparatus visits a plurality of target locations on the two-dimensional layer or surface, and decides, for each target location or a group of target locations, whether or not the target location or group of target locations is to be occupied by building material formulation, and which type of building material formulation is to be delivered

thereto. The decision is made according to a computer image of the surface.
(16) In preferred embodiments of the present invention the AM comprises three-dimensional printing, more preferably three-dimensional inkjet printing. In these embodiments a building material formulation is dispensed from a printing head having one or more arrays of nozzles to deposit building material formulation in layers on a supporting structure. The AM apparatus thus dispenses building material formulation in target locations which are to be occupied and leaves other target locations void. The apparatus typically includes a plurality of arrays of nozzles, each of which can be configured to dispense a different building material formulation. Thus, different target locations can be occupied by different building material formulations. The types of building material formulations can be categorized into two major categories: modeling material formulation and support material formulation. The support material formulation serves as a supporting matrix or construction for supporting the object or object parts during the fabrication process and/or other purposes, e.g., providing hollow or porous objects. Support constructions may additionally include modeling material formulation elements, e.g. for further support strength.
(17) The modeling material formulation is generally a composition which is formulated for use in additive manufacturing and which is able to form a three-dimensional object on its own, i.e., without having to be mixed or combined with any other substance.
(18) The final three-dimensional object is made of the modeling material formulation or a combination of modeling material formulations or modeling and support material formulations or modification thereof (for example, following solidification, e.g., curing). All these operations are well-known to those skilled in the art of solid freeform fabrication.
(19) In some exemplary embodiments of the invention an object is manufactured by dispensing two or more different modeling material formulations, each material formulation from a different array of nozzles (belonging to the same or different printing heads) of the AM apparatus. In some embodiments, two or more such arrays of nozzles that dispense different modeling material formulations are both located in the same printing head of the AM apparatus. In some embodiments, arrays of nozzles that dispense different modeling material formulations are located in separate printing heads, for example, a first array of nozzles dispensing a first modeling material formulation is located in a first printing head, and a second array of nozzles dispensing a second modeling material formulation is located in a second printing head.
(20) In some embodiments, an array of nozzles that dispense a modeling material formulation and an array of nozzles that dispense a support material formulation are both located in the same printing head. In some embodiments, an array of nozzles that dispense a modeling material formulation and an array of nozzles that dispense a support material formulation are located in separate printing heads.
(21) A representative and non-limiting example of a system **10** suitable for AM of an object according to some embodiments of the present invention is illustrated in FIGS. **1**A-C. FIGS. **1**A-C illustrate a top view (FIG. **1**A), a side view (FIG. **1**B) and an isometric view (FIG. **1**C) of system **10**. Preferably, system **10** is a three-dimensional inkjet printing system.
(22) In the present embodiments, system **10** comprises a tray **12** and a plurality of inkjet printing heads **16**, each having one or more arrays of nozzles with respective one or more pluralities of separated nozzles. The material used for the three-dimensional printing is supplied to heads **16** by a building material supply system **42**.
(23) Each printing head is optionally and preferably fed via one or more building material formulation reservoirs (not shown) which may optionally include a temperature control unit (e.g., a temperature sensor and/or a heating device), and a material formulation level sensor.
(24) To dispense the building material formulation, a voltage signal is applied to the printing heads to selectively deposit droplets of material formulation via the printing head nozzles, for example, as in piezoelectric inkjet printing technology. The dispensing rate of each head depends on the number of nozzles, the type of nozzles and the applied voltage signal rate (frequency). Such printing heads

are known to those skilled in the art of solid freeform fabrication.

(25) Tray **12** can have a shape of a disk or it can be annular. Non-round shapes are also contemplated.

(26) Tray **12** and heads **16** are optionally and preferably mounted such as to allow a relative rotary motion between tray **12** and heads **16**. This can be achieved by (i) configuring tray **12** to rotate about a vertical axis **14** relative to heads **16**, (ii) configuring heads **16** to rotate about vertical axis **14** relative to tray **12**, or (iii) configuring both tray **12** and heads **16** to rotate about vertical axis **14** but at different rotation velocities (e.g., rotation at opposite direction). While some embodiments of system **10** are described below with a particular emphasis to configuration (i) wherein the tray is a rotary tray that is configured to rotate about vertical axis **14** relative to heads **16**, it is to be understood that the present application contemplates also configurations (ii) and (iii) for system **10**. Any one of the embodiments of system **10** described herein can be adjusted to be applicable to any of configurations (ii) and (iii), and one of ordinary skills in the art, provided with the details described herein, would know how to make such adjustment. Further, while some embodiments of system **10** are described below with a particular emphasis to rotary AM systems, the present disclosure also contemplates embodiments in which the AM system is non-rotary, wherein the relative motion between the heads and the tray is translational, e.g., along straight lines. Representative examples of such an AM system that is suitable for some embodiments are found in U.S. Pat. No. 10,611,136, the contents of which are hereby incorporated by reference.

(27) In the following description, a direction parallel to tray **12** and pointing outwardly from axis **14** is referred to as the radial direction r, a direction parallel to tray **12** and perpendicular to the radial direction r is referred to herein as the azimuthal direction φ, and a direction perpendicular to tray **12** is referred to herein is the vertical direction z.

(28) Generally, as will be explained below, the rotatory motion between the tray and the printing head(s) of the system allows the heads to scan the tray along the azimuthal direction while dispensing building material thereon. Thus, the azimuthal direction is interchangeably referred to herein as the “scanning direction”. Typically, the printing head(s) comprise an array of nozzles that are at an angle (typically a right angle) to the scanning direction, so that a particular printing head can dispense several rows of building material, each row extending along the scanning direction. Thus, the radial direction is interchangeably referred to herein as the “indexing direction”, indicating that the rows can be indexed along this direction.

(29) It is appreciated, that when the AM system is non-rotary, there is no radial and azimuthal directions. Yet, in non-rotary systems a printing head with an array of nozzles can still scan the tray to form rows of building material. Thus, a similar terminology is also used for non-rotary systems, wherein the direction along which the head scans the tray is referred to as the “scanning direction” and the horizontal direction that perpendicular to the scanning direction is referred to as the “indexing direction.” Oftentimes in the literature, the scanning direction is referred to as the X direction and the indexing direction is referred to as the Y direction.

(30) The term “radial position,” as used herein, refers to a position on or above tray **12** at a specific distance from axis **14**. When the term is used in connection to a printing head, the term refers to a position of the head which is at specific distance from axis **14**. When the term is used in connection to a point on tray **12**, the term corresponds to any point that belongs to a locus of points that is a circle whose radius is the specific distance from axis **14** and whose center is at axis **14**.

(31) The term “azimuthal position,” as used herein, refers to a position on or above tray **12** at a specific azimuthal angle relative to a predetermined reference point. Thus, radial position refers to any point that belongs to a locus of points that is a straight line forming the specific azimuthal angle relative to the reference point.

(32) The term “vertical position,” as used herein, refers to a position over a plane that intersect the vertical axis **14** at a specific point.

(33) Tray **12** serves as a building platform for three-dimensional printing. The working area on

which one or objects are printed is typically, but not necessarily, smaller than the total area of tray **12**. In some embodiments of the present invention the working area is annular. The working area is shown at **26**. In some embodiments of the present invention tray **12** rotates continuously in the same direction throughout the formation of object, and in some embodiments of the present invention tray reverses the direction of rotation at least once (e.g., in an oscillatory manner) during the formation of the object. Tray **12** is optionally and preferably removable. Removing tray **12** can be for maintenance of system **10**, or, if desired, for replacing the tray before printing a new object. In some embodiments of the present invention system **10** is provided with one or more different replacement trays (e.g., a kit of replacement trays), wherein two or more trays are designated for different types of objects (e.g., different weights) different operation modes (e.g., different rotation speeds), etc. The replacement of tray **12** can be manual or automatic, as desired. When automatic replacement is employed, system **10** comprises a tray replacement device **36** configured for removing tray **12** from its position below heads **16** and replacing it by a replacement tray (not shown). In the representative illustration of FIG. **1**A tray replacement device **36** is illustrated as a drive **38** with a movable arm **40** configured to pull tray **12**, but other types of tray replacement devices are also contemplated.

(34) Exemplified embodiments for the printing head **16** are illustrated in FIGS. **2**A-**2**C. These embodiments can be employed for any of the AM systems described above, including, without limitation, rotary system **10** and non-rotary systems.

(35) FIGS. **2**A-B illustrate a printing head **16** with one (FIG. **2**A) and two (FIG. **2**B) nozzle arrays **22**. The nozzles in the array are preferably aligned linearly, along a straight line. In embodiments in which a particular printing head has two or more linear nozzle arrays, the nozzle arrays are optionally and preferably can be parallel to each other. When a printing head has two or more arrays of nozzles (e.g., FIG. **2**B) all arrays of the head can be fed with the same building material formulation, or at least two arrays of the same head can be fed with different building material formulations.

(36) When a non-rotary system with multiple printing heads is employed, all printing heads are optionally and preferably oriented along the indexing direction with their positions along the scanning direction being offset to one another.

(37) When a system similar to system **10** is employed, all printing heads **16** are optionally and preferably oriented radially (parallel to the radial direction) with their azimuthal positions being offset to one another. Thus, in these embodiments, the nozzle arrays of different printing heads are not parallel to each other but are rather at an angle to each other, which angle being approximately equal to the azimuthal offset between the respective heads. For example, one head can be oriented radially and positioned at azimuthal position φ.sub.1, and another head can be oriented radially and positioned at azimuthal position φ.sub.2. In this example, the azimuthal offset between the two heads is φ.sub.1-φ.sub.2, and the angle between the linear nozzle arrays of the two heads is also φ.sub.1-φ.sub.2.

(38) In some embodiments, two or more printing heads can be assembled to a block of printing heads, in which case the printing heads of the block are typically parallel to each other. A block including several inkjet printing heads **16***a*, **16***b*, **16***c* is illustrated in FIG. **2**C.

(39) In some embodiments, system **10** comprises a stabilizing structure **30** positioned below heads **16** such that tray **12** is between stabilizing structure **30** and heads **16**. Stabilizing structure **30** may serve for preventing or reducing vibrations of tray **12** that may occur while inkjet printing heads **16** operate. In configurations in which printing heads **16** rotate about axis **14**, stabilizing structure **30** preferably also rotates such that stabilizing structure **30** is always directly below heads **16** (with tray **12** between heads **16** and tray **12**).

(40) Tray **12** and/or printing heads **16** is optionally and preferably configured to move along the vertical direction z, parallel to vertical axis **14** so as to vary the vertical distance between tray **12** and printing heads **16**. In configurations in which the vertical distance is varied by moving tray **12**

along the vertical direction, stabilizing structure **30** preferably also moves vertically together with tray **12**. In configurations in which the vertical distance is varied by heads **16** along the vertical direction, while maintaining the vertical position of tray **12** fixed, stabilizing structure **30** is also maintained at a fixed vertical position.

(41) The vertical motion can be established by a vertical drive **28**. Once a layer is completed, the vertical distance between tray **12** and heads **16** can be increased (e.g., tray **12** is lowered relative to heads **16**) by a predetermined vertical step, according to the desired thickness of the layer subsequently to be printed. The procedure is repeated to form a three-dimensional object in a layerwise manner.

(42) The operation of inkjet printing heads **16** and optionally and preferably also of one or more other components of system **10**, e.g., the motion of tray **12**, are controlled by a controller **20**. The controller can have an electronic circuit and a non-volatile memory medium readable by the circuit, wherein the memory medium stores program instructions which, when read by the circuit, cause the circuit to perform control operations as further detailed below.

(43) Controller **20** can also communicate with a host computer **24** which transmits digital data pertaining to fabrication instructions based on computer object data, e.g., in a form of a Standard Tessellation Language (STL) or a StereoLithography Contour (SLC) format, Virtual Reality Modeling Language (VRML), Additive Manufacturing File (AMF) format, Drawing Exchange Format (DXF), Polygon File Format (PLY) or any other format suitable for Computer-Aided Design (CAD). The object data formats are typically structured according to a Cartesian system of coordinates. In these cases, computer **24** preferably executes a procedure for transforming the coordinates of each slice in the computer object data from a Cartesian system of coordinates into a polar system of coordinates. Computer **24** optionally and preferably transmits the fabrication instructions in terms of the transformed system of coordinates. Alternatively, computer **24** can transmit the fabrication instructions in terms of the original system of coordinates as provided by the computer object data, in which case the transformation of coordinates is executed by the circuit of controller **20**.

(44) The transformation of coordinates allows three-dimensional printing over a rotating tray. In non-rotary systems with a stationary tray with the printing heads typically reciprocally move above the stationary tray along straight lines. In such systems, the printing resolution is the same at any point over the tray, provided the dispensing rates of the heads are uniform. In system **10**, unlike non-rotary systems, not all the nozzles of the head points cover the same distance over tray **12** during at the same time. The transformation of coordinates is optionally and preferably executed so as to ensure equal amounts of excess material formulation at different radial positions. Representative examples of coordinate transformations according to some embodiments of the present invention are provided in FIGS. **3**A-B, showing three slices of an object (each slice corresponds to fabrication instructions of a different layer of the objects), where FIG. **3**A illustrates a slice in a Cartesian system of coordinates and FIG. **3**B illustrates the same slice following an application of a transformation of coordinates procedure to the respective slice.

(45) Typically, controller **20** controls the voltage applied to the respective component of the system **10** based on the fabrication instructions and based on the stored program instructions as described below.

(46) Generally, controller **20** controls printing heads **16** to dispense, during the rotation of tray **12**, droplets of building material formulation in layers, such as to print a three-dimensional object on tray **12**.

(47) The inkjet printing heads dispense layers of building material via inkjet technology. Each of the printing heads can be configured to dispense a different building material. When a particular printing head comprises two or more nozzle arrays, each nozzle array can be configured to dispense a different building material. Thus, different target locations can be occupied by different building materials.

(48) The type of material that is conveyed to each nozzle array of each printing head for dispensing is optionally and preferably controlled by controller **20**. For example, controller **20** can signal a building material supply system **42** to supply a first modeling material to one nozzle array of a first head and a support material to another nozzle array of the first head. Controller **20** can also signal system **42** to supply the first modeling material to one nozzle array of the first head, the support material to another nozzle array of the first head, and a second modeling material to one nozzle array of a second head. Alternatively, controller **20** can signal system **42** to supply the support material to a nozzle array of another head. Controller **20** can also signal system **42** to supply the first modeling material to one nozzle array of the first head, the support material to another nozzle array of the first head, the second modeling material to one nozzle array of the second head, and a third modeling material to another nozzle array of the second head, and so on.
(49) System **10** optionally and preferably comprises a solidification system **18** for solidifying (e.g., curing) the building material formulation. Solidification system **18** can comprise one or more radiation sources **18**, which can be, for example, an ultraviolet or visible or infrared lamp, or other sources of electromagnetic radiation, or electron beam source, depending on the modeling material formulation being used. Radiation source can include any type of radiation emitting device, including, without limitation, light emitting diode (LED), digital light processing (DLP) system, resistive lamp and the like. In various exemplary embodiments of the invention the operation of solidification system **18** is controlled by controller **20** which may activate and deactivate solidification system **18**. When solidification system comprises a radiation source, controller **20** optionally also control the amount of radiation generated by the radiation source.
(50) In some embodiments of the present invention radiation source **18** is configured to reciprocally move relative to tray along the radial direction r. These embodiments are useful when the length of radiation source **18** is shorter than the width along the radial direction of the working area **26** on tray **12**. The motion of radiation source **18** along the radial direction is optionally and preferably controlled by controller **20**. Thus, the present embodiments contemplate a radiation source and a printing head, each being independently controllable to move in the radial direction along a separate motion stage. This is unlike conventional three-dimensional printing systems in which the printing head and radiation source are mounted on the same printing block and are therefore forced to move simultaneously. In some embodiments of the invention controller **20** is configured to move radiation source **18** and head(s) **16** non-simultaneously along the radial direction during the operation of system **10**. In some embodiments of the invention controller **20** is configured to move radiation source **18** and head(s) **16** non-simultaneously independently along the radial direction during the operation of system **10**. These embodiments are particularly useful when it is desired to select the time at which solidification (e.g., curing) is initiated, for example, to delay the solidification.
(51) In some embodiments of the invention, system **10** further comprises one or more leveling devices **32** which can be manufactured as a roller or a blade. Leveling device **32** serves to straighten the newly formed layer prior to the formation of the successive layer thereon. In some embodiments, leveling device **32** has the shape of a conical roller positioned such that its symmetry axis **34** is tilted relative to the surface of tray **12** and its surface is parallel to the surface of the tray. This embodiment is illustrated in the side view of system **10** (FIG. **1**B). The conical roller can have the shape of a cone or a conical frustum.
(52) The operation of leveling device **32** is optionally and preferably controlled by controller **20** which may activate and deactivate leveling device **32** and may optionally also control its position along a vertical direction (parallel to axis **14**) and/or a radial direction (parallel to tray **12** and pointing toward or away from axis **14**.
(53) The printing head(s) **16**, the solidification system **18**, and optionally and preferably also the leveling device(s) **32** form a printing block of system **10**, and are typically mounted on a structure such as a frame **128**.

(54) In some embodiments of the present invention printing heads **16** are configured to reciprocally move relative to tray along the radial direction r. These embodiments are useful when the lengths of the nozzle arrays **22** of heads **16** are shorter than the width along the radial direction of the working area **26** on tray **12**. The motion of heads **16** along the radial direction is optionally and preferably controlled by controller **20**.
(55) Some embodiments contemplate the fabrication of an object by dispensing different material formulations from different arrays of nozzles (belonging to the same or different printing head). These embodiments provide, inter alia, the ability to select material formulations from a given number of material formulations and define desired combinations of the selected material formulations and their properties. According to the present embodiments, the spatial locations of the deposition of each material formulation with the layer is defined, either to effect occupation of different three-dimensional spatial locations by different material formulations, or to effect occupation of substantially the same three-dimensional location or adjacent three-dimensional locations by two or more different material formulations so as to allow post deposition spatial combination of the material formulations within the layer, thereby to form a composite material formulation at the respective location or locations.
(56) Any post deposition combination or mix of modeling material formulations is contemplated. For example, once a certain material formulation is dispensed it may preserve its original properties. However, when it is dispensed simultaneously with another modeling material formulation or other dispensed material formulations which are dispensed at the same or nearby locations, a composite material formulation having a different property or properties to the dispensed material formulations may be formed.
(57) In some embodiments of the present invention the system dispenses digital material for at least one of the layers.
(58) The phrase "digital materials", as used herein and in the art, describes a combination of two or more materials on a pixel level or voxel level such that pixels or voxels of different materials are interlaced with one another over a region. Such digital materials may exhibit new properties that are affected by the selection of types of materials and/or the ratio and relative spatial distribution of two or more materials.
(59) As used herein, a "voxel" of a layer refers to a physical three-dimensional elementary volume within the layer that corresponds to a single pixel of a bitmap describing the layer. The size of a voxel is approximately the size of a region that is formed by a building material, once the building material is dispensed at a location corresponding to the respective pixel, leveled, and solidified.
(60) The present embodiments thus enable the deposition of a broad range of material formulation combinations, and the fabrication of an object which may consist of multiple different combinations of material formulations, in different parts of the object, according to the properties desired to characterize each part of the object.
(61) It is expected that during the life of a patent maturing from this application many relevant AM systems will be developed and the scope of the term AM system is intended to include all such new technologies a priori.
(62) Following the completion of the printing process object, the printed object is removed from the tray. Since the bottommost layer of the object is typically attached to the tray, removal of the printed object typically involves the use of a scraper or a similar tool. In three-dimensional printing systems in which the tray is rotary (e.g., system **10**), it is difficult to remove the object while the tray is free to rotate since the scraping operation moves the tray. It is therefore desired to have a locking mechanism that locks the tray from moving during removal of the objects. It is also desirable to have a locking mechanism that locks the tray from moving during maintenance of different components of the system.
(63) The inventors found that while a locking mechanism is advantageous for the reasons stated above, the use of a locking mechanism is susceptible to human errors (e.g., failing to unlock the

tray before commencing a new printing job) that would best be avoided. The inventors have therefore devised a safety system for a rotary tray of a three-dimensional printing system, such as, but not limited to, the rotary tray **12** of system **10**.

(64) FIGS. **4**A and **4**B are schematic illustrations showing a top view of a printing chamber **400** having an access opening **402**, and a door **404** at access opening **402**. Printing chamber **400** is dimensionally designed to contain the rotary tray **12**, and optionally and preferably also other components of the printing system, such as the printing block or frame **128** (not shown in FIGS. **4**A and **4**B, see FIG. **1**C) as further detailed hereinabove. Door **404** is preferably a rotating door, as illustrated in FIGS. **4**A and **4**B, but in some embodiments of the present invention, the door can be a sliding door. A safety system **410** is introduced in chamber **400**, which safety system **410** comprises a door state sensor **412**, configured for generating a signal indicating whether door **404** is open or closed, and a latch **414** which is constructed to assume a locked state (FIG. **4**B) in which latch **414** prevents door **404** from closing and tray **12** from rotating, and an unlocked state (FIG. **4**A) in which latch **414** allows door **404** to close and the tray to rotate. Side views of printing chamber **400** in a closed state and an open state of door **404** are illustrated in FIGS. **4**C and **4**D, respectively.

(65) Latch **414** is preferably a manually operated latch. In the preferred configuration illustrated in FIGS. **4**A and **4**B, latch **414** reciprocally slides radially with respect to the tray **12**, wherein when latch **414** is retracted inwardly latch **414** assumes the unlocked state, and when latch **414** is extracted outwardly latch **414** assumes the locked state. For example, as illustrated in FIG. **4**B, latch **414** can protrude out of access opening **402** when extracted outwardly, thereby preventing door **404** from closing. In other embodiments, latch **414** can be constructed to pivot rather than to slide radially. Latch **414** can also be configured to prevent the door from closing indirectly by actuating a mechanism (not shown) that locks the door's hinge.

(66) Door state sensor **412** can be of any type, including, without limitation, a magnetic sensor, an optical sensor, and an electromechanical switch. The signal generated by sensor **412** is preferably transmitted to the controller of the printing system (not shown, see, e.g., controller **20** in FIG. **1**A). In response to this signal, the controller activates or deactivates the various components of the three-dimensional printing system. For example, when the signal from sensor **412** indicates that the door is open, the controller can deactivate all printing operations, including the deactivation of the nozzle arrays **16**, the leveling device **32** and the solidification system **18**.

(67) Thus, the combined operations of sensor **412** and latch **414** of safety system **410** provide the printing system **10** with additional safety measures, since latch **414** maintains the door **404** open while tray **12** is locked, and the signal generated by sensor **412** ensures that when the door is open the controller does not resume or initiate a printing job.

(68) FIGS. **5**A-C are schematic illustrations showing perspective views of latch **414**, in the unlocked (FIGS. **5**A and **5**C) and locked (FIG. **5**B) states, according to some embodiments of the present invention. FIGS. **5**A and **5**B also illustrate a platter **452** for carrying tray **12** (not shown) with a nut **406** fixing the center of platter **452** to its position at the rotation axis **14**. FIG. **5**C shows a perspective view of a platform **450**, carrying platter **452**, and having a driving board **451** carrying latch **414**. Platform **450** is configured to rotate platter **452**, and consequently also tray **12** once mounted thereon, and also to move in the vertical direction as further detailed hereinabove.

(69) Latch **414** comprises a two or more slide slots **422** that slide over respective secured pins **424**, facilitating the reciprocal motion of latch **414** along the radial direction. Pins **424** can be secured, for example, to the driving board **451** of platform **450** (see FIG. **5**C). Latch **414** optionally and preferably comprises a lock member **416** that can engage and be disengaged from platter **452**. Lock member can have the shape of pillar and be embodied, e.g., as a pin or a screw. In the unlocked state (FIG. **5**A), lock member **416** is disengaged from platter **452**, thereby allowing platter **452** and tray **12** to rotate. In the locked state (FIG. **5**B), lock member **416** engages platter **452** in a manner that prevents platter **452** and tray **12** from rotating. Preferably, a sprocket wheel **418** is connected to

the tray to rotate therewith. In these embodiments, lock member **416** engages sprocket wheel **418** in the locked state, and disengages from sprocket wheel **416** in the unlocked state.

(70) Platform **450** preferably comprises one or more supporting rollers **454** for supporting tray **12** during its rotation. The inventors found that it is advantageous to have at least one of the supporting rollers **454** under the tray below the leveling device (not shown see FIGS. **1**A-C), for absorbing a force applied by the leveling device. An additional supporting roller **454** is optionally and preferably mounted on latch **414**.

(71) In some embodiments of the present invention safety system **410** comprises one or more springs **420** arranged to bias latch **414** to maintain the locked state upon activation of latch **414**. Preferably, latch **414** is a push-push latch, so that when latch **414** is in its unlocked state, a small movement of latch **414** inwardly (over-pushing), releases the springs **420** that in turn move latch **414** outwardly and there is no need to apply manual force outwardly. To return latch **414** from its locked state to its unlocked states, a force is applied to latch **414**, against the forces of the springs **420**, throughout the displacement length of latch **414** from the extracted position to the retracted position.

(72) The advantage of constructing the springs **420** to bias latch **414** to maintain the locked state upon activation of latch **414**, is that since the springs **420** apply the force outwardly, they prevent the door **404** from being closed, thereby indirectly preventing the printing job from commencing or resuming while the tray is locked. In tests performed by the inventors, it was unexpectedly found that during some operations, application of a firm force on the door may result in a situation in which the door is closed but the tray is still locked. In such a situation the controller, which receives a signal indicating that the door is closed, may commence or resume the printing job while the tray is not rotating. Even is controller does receive indication the tray is not rotating (e.g., from other sensors of the printing system), it may generate an alert message and require the user to run a security maintenance check, which would best be avoided.

(73) To overcome this problem, the inventors devised a double lock safety principle that prevents the door from being closed while latch **414** is in its extracted position. The double lock safety principle will now be explained with reference to FIG. **6**A-C.

(74) FIGS. **6**A-C are schematic illustrations showing a perspective bottom view (FIG. **6**A) and side views (FIGS. **6**B and **6**C) of latch **414** according to some embodiments of the present invention. Shown is latch **414** in its extracted (FIGS. **6**A and **6**B), and retracted (FIG. **6**C) positions.

(75) In the illustrated embodiment, an elastic lever **430** is connected to latch **414** (at its bottom side, in the present example). Lever **430** can be embodied, for example, by a plate, such as, but not limited to, a metal plate. A stopper element **432**, such as a screw or the like can be mounted at a fixed radial distance from the vertical axis **14**, for example, on driving board **451** of platform **450** (FIG. **5**C). In some embodiments of the present invention stopper element **432** passes through slide slots **422** or one or more additional slide slots **434** formed in latch **414**, so that stopper element **430** remains fixed when latch **414** slides. When lever **430** is in a relaxed state (FIGS. **6**A and **6**B) a force applied to latch **414** inwardly results in a collision between lever **430** and stopper element **432**, preventing latch **414** from retracting and assuming its unlocked state. FIG. **6**C illustrates lever **430** in a strained state, after a force **436** is applied to its distal end upwardly. In this state, lever **430** bypasses stopper element **432**, allowing latch **414** to retract and assume its unlocked state.

(76) FIG. **7** is a schematic illustration showing an exploded view of platter **452** on vertical axis **14**, according to some embodiments of the present invention. Axis **14** optionally and preferably is formed with a central shoulder **440** supporting platter **452**. Typically, platter **452** is fixed on shoulder **440** by means of a horseshoe spring **442**. The inventors found that stresses applied to platter **452** during the removal of the printed object from platter **452**, deflects horseshoe spring **442**. The inventors unexpectedly discovered that in time these occasional deflections become permanent, and that such permanent deflection affects the centrality and/or planarity of the rotation of the tray and reduces the print quality.

(77) The inventors found that latch **414** can also be utilized to reduce the stress on horseshoe spring **442**, hence improve the print quality of system **10**. This embodiment is schematically illustrated in FIGS. **8**A and **8**B, showing latch **414** in its unlocked (FIG. **8**A) and locked (FIG. **8**B) states. In these embodiments, lock member **416** is provided with a widened head **447**, such as a screw head, and the height **446** of lock member **416** and its head **447** is selected to support platter **452** in the locked state. This reduces the stress on axis **14** and consequently horseshoe spring **442** while platter **452** is locked, since vertical forces applied, for example, by the user during the removal of the object from the tray, are distributed between horseshoe spring **442** and lock member **416**. The inventors found that this significantly increases the lifetime of spring **442**. Preferably, the height **446** of lock member is selected to support platter **452** in the locked state but not in the unlocked state. This can be achieved, for example, by providing a platter having a profile that is not planar at its bottom side. Specifically, in these embodiments platter **452** has thickness that is larger at its periphery than at or near its center, so that when latch **414** is extracted, lock member **416** supports the thicker peripheral part of the platter **452**, and latch **414** is retracted, there is a gap between the head **447** and the thinner non-peripheral part of platter **452**.
(78) As used herein the term “about” or “approximately” refers to ±10%.
(79) The word “exemplary” is used herein to mean “serving as an example, instance or illustration.” Any embodiment described as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments and/or to exclude the incorporation of features from other embodiments.
(80) The word “optionally” is used herein to mean “is provided in some embodiments and not provided in other embodiments.” Any particular embodiment of the invention may include a plurality of “optional” features unless such features conflict.
(81) The terms “comprises”, “comprising”, “includes”, “including”, “having” and their conjugates mean “including but not limited to”.
(82) The term “consisting of” means “including and limited to”.
(83) The term “consisting essentially of” means that the composition, method or structure may include additional ingredients, steps and/or parts, but only if the additional ingredients, steps and/or parts do not materially alter the basic and novel characteristics of the claimed composition, method or structure.
(84) As used herein, the singular form “a”, “an” and “the” include plural references unless the context clearly dictates otherwise. For example, the term “a compound” or “at least one compound” may include a plurality of compounds, including mixtures thereof.
(85) Throughout this application, various embodiments of this invention may be presented in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the invention. Accordingly, the description of a range should be considered to have specifically disclosed all the possible subranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed subranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.
(86) Whenever a numerical range is indicated herein, it is meant to include any cited numeral (fractional or integral) within the indicated range. The phrases “ranging/ranges between” a first indicate number and a second indicate number and “ranging/ranges from” a first indicate number “to” a second indicate number are used herein interchangeably and are meant to include the first and second indicated numbers and all the fractional and integral numerals therebetween.
(87) It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a

single embodiment, may also be provided separately or in any suitable subcombination or as suitable in any other described embodiment of the invention. Certain features described in the context of various embodiments are not to be considered essential features of those embodiments, unless the embodiment is inoperative without those elements.
(88) Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims.
(89) All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated herein by reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention. To the extent that section headings are used, they should not be construed as necessarily limiting. In addition, any priority document(s) of this application is/are hereby incorporated herein by reference in its/their entirety.

Claims

1. A safety system for a rotary tray of a three-dimensional printing system, the printing system having a printing head, a controller, and a printing chamber with an access opening, the safety system comprising a door state sensor, configured for transmitting to the controller a signal indicative whether a door at said access opening is open or closed; and a latch having a lock member and being operable to assume a locked state in which said latch prevents said door from closing while said lock member prevents the tray from rotating, and an unlocked state in which said latch allows said door to close while said lock member allows the tray to rotate.
2. The system according to claim 1, further comprising a sprocket wheel connected to the tray to rotate therewith, wherein said lock member engages said sprocket wheel in said locked state, and disengages from said sprocket wheel in said unlocked state.
3. The system according to claim 1, wherein said latch is operable to reciprocally slide radially with respect to the tray, wherein when said latch is extracted outwardly said latch assumes said locked state, and when said latch is retracted inwardly said latch assumes said unlocked state.
4. The system according to claim 3, wherein said latch protrudes out of the access opening when extracted outwardly, thereby preventing said door from closing.
5. The system according to claim 1, further comprising a spring constituted to bias said latch to maintain said locked state upon activation of said latch.
6. The system according to claim 1, further comprising an elastic lever connected to said latch in a manner that when said lever is in a relaxed state, said lever collides with a stopper element and prevents said latch from assuming said unlocked state, and when said lever is in a strained state said lever bypasses said stopper element allowing said latch to assume said unlocked state.
7. The system according to claim 1, wherein a height of said lock member is selected to support the tray in said locked state.
8. The system according to claim 1, wherein a height of said lock member is selected to support the tray in said locked state but not in said unlocked state.
9. The system according to claim 1, wherein said latch is a push-push latch.
10. A three-dimensional printing system, comprising a printing head, a rotary tray, a controller, a printing chamber with an access opening, and the safety system according to claim 1.
11. A method of printing a three-dimensional object, comprising: receiving three-dimensional printing data corresponding to the shape of the object; feeding said data to the three-dimensional printing system of claim 10; operating the three-dimensional printing system to print the object;

opening said door of said printing chamber; activating said latch to lock said tray; and removing said object from said tray.