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United States Patent Application Publication	20250263181
Kind Code	A1
Publication Date	August 21, 2025
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IN-SITU APPLICATION OF ADAPTIVE LEVELS OF ENERGY APPLIED TO A SUBSET OF INDIGENOUS PARTICULATE TO FORM STRUCTURES IN A VACUUM

Abstract

Various embodiments relate generally to additive manufacturing and construction techniques to form structures with embodiments directed to computer software and systems, and control systems, and, more specifically, to a computing and a mechanical platform configured to implement local material to form a structure by selecting or filtering a subset of particulate that is deposited in a form at which adaptive levels of energy are applied to construct structures in-situ in a vacuum additively (e.g., three-dimensionally, or in "3D"), whereby adaptive levels of energy may be generated by one or more lasers and may be configurable to control temperatures associated with, for example, crystallization of indigenous particulate.

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Appl. No.: **18/444565**

Filed: **February 16, 2024**

Publication Classification

Int. Cl.: **B64G99/00** (20090101); **B33Y10/00** (20150101); **B33Y30/00** (20150101); **E04G21/04** (20060101)

U.S. Cl.:

CPC **B64G99/00** (20220801); **E04G21/04** (20130101); B33Y10/00 (20141201); B33Y30/00 (20141201)

Background/Summary

FIELD
[0001] Various embodiments relate generally to additive manufacturing and construction techniques to form structures with embodiments directed to computer software and systems, and control systems, and, more specifically, to a computing and a mechanical platform configured to implement local material to form a structure by selecting or filtering a subset of particulate that is deposited in a form at which adaptive levels of energy are applied to construct structures in-situ in a vacuum additively (e.g., three-dimensionally, or in “3D”), whereby adaptive levels of energy may be generated by one or more lasers and may be configurable to control temperatures associated with, for example, crystallization of indigenous particulate.
BACKGROUND
[0002] Advances in robotics, computing hardware, software, and material science has contributed to various improvements to provide materials for construction of any type of structure, such as a wall, by using one or more viscous materials to form a “bead” or a longitudinally formed material.
[0003] Generally, typical construction techniques are directed to employ one or more materials local to a worksite at which to construct a structure having vertical dimensions, such as a wall, or horizontal dimensions, such as slab or a floor. But types and qualities of materials at certain locations present challenges on implementing indigenous construction materials suitable for additively forming structures, such as three-dimensional printed structures (e.g., “3D” printed structures). While some conventional approaches are functional in some environments, such approaches are not well-suited for other environments. Specifically, various conventional approaches to forming 3D structures implementing terrestrial materials are generally ill-suited for using materials that are other than terrestrial.
[0004] Some conventional approaches to using non-terrestrial (e.g., “off planet”) materials, or simulants thereof-including lunar simulants, have yet to be shown as optimal approaches to additive construction of structures. As an example, using known binder-based mortars with non-terrestrial materials are generally sub-optimum for forming structures in-situ. Moreover, known selective laser sintering (“SLS”) techniques are usually restricted to terrestrial use (e.g., in terms of gravity, atmospheric pressures levels, temperatures, etc.) and are directed to known characteristics (e.g., known sizes, known material compositions, etc.) of a material used. Thus, such terrestrial-limited approaches do not implement materials in-situ and likely are not adapted for non-terrestrial uses.
[0005] Thus, what is needed is a solution to forming structures implementing non-terrestrial materials in a vacuum, without the limitations of conventional techniques.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0006] Various embodiments or examples (“examples”) of the invention are disclosed in the following detailed description and the accompanying drawings:
[0007] FIG. **1** is a diagram depicting an example of a device configured to implement a subset of indigenous particulate to form a structure in-situ, according to some embodiments;
[0008] FIG. **2** is a diagram depicting an example of an integrated end effector coupled to a robotic

articulator, according to at least one example;

[0009] FIG. **3** is a perspective view of an example of an integrated end effector, according to some embodiments;

[0010] FIG. **4** illustrates an example of a thermal profile for a layer of particulate during application of laser energy, according to some examples;

[0011] FIGS. **5**A and **5**B depict exemplary structures or sub-structures additively constructed, according to some examples;

[0012] FIG. **6** depicts an example flow with which to form a structure or sub-structure, according to some embodiments;

[0013] FIG. **7** depicts another example flow with which to form multiple structures or sub-structures, according to some embodiments;

[0014] FIG. **8** illustrates an exemplary application architecture for controlling in-situ application of adaptive levels of energy applied to a subset of indigenous particulate to form structures in a vacuum, according to some examples; and

[0015] FIG. **9** illustrates examples of various computing platforms configured to provide various functionalities to components of a computing platform configured to provide functionalities described herein.

DETAILED DESCRIPTION

[0016] Various embodiments or examples may be implemented in numerous ways, including as a system, a process, an apparatus, a user interface, or a series of program instructions on a computer readable medium such as a computer readable storage medium or a computer network where the program instructions are sent over optical, electronic, or wireless communication links including wireless transmissions between earth and off-planet computing devices. In general, operations of disclosed processes may be performed in any arbitrary order, unless otherwise provided in the claims.

[0017] A detailed description of one or more examples is provided below along with accompanying figures. The detailed description is provided in connection with examples and is not limited to any particular example. The scope is limited only by the claims, and numerous alternatives, modifications, and equivalents thereof. Numerous specific details are set forth in the following description to provide a thorough understanding. These details are provided for the purpose of example and the described techniques may be practiced according to the claims without some or all of these specific details. For clarity, technical material that is known in the technical fields related to the examples has not been described in detail to avoid unnecessarily obscuring the description or providing unnecessary details that may be already known to those of ordinary skill in the art.

[0018] FIG. **1** is a diagram depicting an example of a device configured to implement a subset of indigenous particulate to form a structure in-situ, according to some embodiments. Diagram **100** depicts examples of a device configured to identify particulate for acquisition, to select a subset of particulate, and to form additive layers from which a structure may be constructed additively. In diagram **100**, an example of a device is an integrated end effector **112** configured to perform exemplary functions or operations shown as operation **110**, operation **120**, and operation **130**, at least in some cases. Integrated end effector **112** may be configured to perform each of operations **110**, **120**, and **130** any number of times and may be further configured to perform other functions or operations not depicted in diagram **100**. In at least some examples, integrated end effector **112** may include a power unit **136** that includes one or more lasers configured to direct programmable energy to an unenclosed filtered indigenous particulate in a vacuum. Integrated end effector **112** may be configured to form structures, such as habitats, residences, roads, landing pads (e.g., lander and rocketry landing pads), blast shields, semi-open structures (e.g., hangers or garages), as well as any other structure formable in-situ with integrated end effector **112**.

[0019] In operation **110**, integrated end effector **112** may be configured to identify via sensors a portion **113** of a worksite associated with soil **111** from which to collect particulate. Integrated end effector **112** is shown to include a scoop **116** configured to extract or obtain indigenous particulate **114** from soil **111**. As shown, integrated end effector **112** is in a state at which particulate **114** is scooped up or otherwise extracted. An example of particulate **114** may be composed of particles **104***a* and particles **104***b*, whereby particles **104***a* and **104***b* may be regolith, such as non-terrestrial regolith including lunar regolith, planetary regolith (e.g., Mars regolith), asteroid regolith, or the like. Particulate **114** may include any other combination of any solid material, such as rock-like particles of any size and possibly combined with any mineral or element and may be characterized based on its composition. For example, particles **104***a* and particles **104***b*, as constituents of particulate **114**, may be characterized by agglutinate content or amounts of associated solar wind gases. Note that while a scoop **116** is shown, any other mechanism or means to extract particulate **114** may be performed by integrated end effector **112**, such as by any mechanical or robotic grasping techniques, as well by any other means (e.g., vacuuming up particulate **114** into integrated end effector **112**). Thus, integrated end effector **112** need not be limited to implement scoop **116** to extract particulate **114**. In various examples, soil **111** may include non-terrestrial soil, such as lunar soil and planetary soil, as well as terrestrial soil (e.g., particulate **114** may include terrestrial particles in some implementations).

[0020] In operation **120**, integrated end effector **112** may be configured to select one or more subsets of particulate from extracted particulate **114** to include in formation of additively constructed structures. In this example, scoop **116** may include a filter **124** configured to filter out (i.e., select) at least one subset of extracted particulate **114** as a source particulate **122**. While not shown, non-filtered portions of extracted particulate **114** may remain in scoop **116**. The non-filtered particulate may be deemed discardable, and thus integrated end effector **112** may be configured to move to spatially discard the non-filtered particulate into a collection or pile of discharged particulate **121** at a location suitably away from a worksite as which a structure is being formed. In some examples, filter **124** may be configured to selectively separate one or more subsets of source particulate **122**. Filter **124** may also include any number of filters each of which being configured to filter a specific subset of source particulate **122**. In some examples, filter **124** may be configured to select source particulate **122** as a function of particle size. For example, filter **124** may be configured to filter particles less than 1 mm in one or more dimensions. So, if particle **104***b* is less than 1 mm and particle **104***a* is greater than 1 mm, filter **124** may function to select particle **104***b* as source particulate **122** and may further select particle **104***a* as discharged particulate **121**. Note that one or more filters **124** may operate to select particulate at any size. Further, filter **124** may be configured to filter or select source particulate **122** on characteristics other than size. For example, filter **124** may be configured to select source particulate **122** as a function of mineral composition or any other characteristic.

[0021] Further to operation **120**, scoop **116** of integrated end effector **112** may collect a portion of source particulate **122** and deposit or dispense that portion of source particulate **122** at a target location of a worksite. For example, integrated end effector **112** may dispense source particulate **122** in a linear form as a layer **134**. Note, however, integrated end effector **112** is not limited to dispensing source particulate **122** in a linear form but can deposit source particulate **122** in any geometric shape, such as a curved or arcuate form, or any other shape for any layer **134**. Once formed, one or more layers **134** may include various linear layers and/or layers having various degrees of curvature. Hence, integrated end effector **112** may be configured to additively manufacture a structure of any variation of vertical and horizontal dimensions.

[0022] Also, integrated end effector **112** may be configured to compress or tamp source particulate **122** that is dispensed as a layer **134** to remove or decrease spaces among particles **104***b* (i.e., increase density of selected regolith). As shown in operation **120**, integrated end effector **112** may include a compression surface unit **128**, which, in some cases, may be a surface (e.g., the bottom) of a chassis configured to apply a force to compress or tamp layer **134**.

[0023] At operation **130**, integrated end effector **112** is shown to include a power unit **136** to apply directed energy **134** to each dispensed and compressed layer of one or more layers **134**, whereby any number of layers **134** may be formed upon each other additively (e.g., 3D printed). In a non-limiting example, power unit **136** may be configured to apply directed energy **135** to layer **134** as a dispensed and compressed layer to transition corresponding source particulate **122** from a first solid state (e.g., as lunar regolith) to a molten state at a first point in time at a first temperature. In some examples, source particulate **122** in a molten state may be formed as an amorphous glass, which may be degassed and homogeneous as a molten liquid. Layer **134** in a molten state may transition into a second solid state, as an annealed solid, that may result in an amorphous glass layer. Also, layer **134**, as an annealed solid, may be degassed, homogeneous, and a non-crystalline or quasi-crystalline sub-structure at a second point in time and at a second temperature (e.g., after directed energy **135** is directly applied and/or a temperature of layer **134** decreases). Thereafter, as a function of temperature and time, layer **134** in a solid state may transition into a state of crystallization. Integrated end effector **112** and power unit **136** are configured to induce crystallization from nucleation so that layer **134** results in an implementable state, such as a ceramic-glass sub-structure, at a third point in time and at a third temperature (or at any other time or temperature).

[0024] In some examples, integrated end effector **112** may receive feedback **137** as sensor data so that integrated end effector **112** may monitor application of energy (and temperature at layer **134**) against a thermal profile (or any other characteristic) to determine whether application of a level of directed energy **135** absorbed at layer **134** conforms with operational tolerances, such as a thermal profile. If non-conformance is determined, integrated end effector **112** may be configured to adapt levels of energy applied to layer **134** to control and induce crystallization optimally to form a ceramic-glass sub-structure (or an equivalent thereof). In some examples, feedback **137** may be generated if a type of source particulate **122** that is receiving directed energy **135** is not producing a layer in accordance with a thermal profile. For example, a combination of certain types of regolith may not track a thermal profile or schedule. Directed energy **135** may be adapted based on feedback **137** to ensure optimal crystallization.

[0025] In various examples, power unit **136** may include one or more lasers

[0026] configured to apply energy for absorption by filtered regolith-in a vacuum-to cause the filtered regolith of source particulate **122** to increase in temperature sufficient to enter a molten state, whereby optimal crystallization may be managed. In one embodiment, operation **130** may include activating one or more lasers as power unit **136** to cause compressed source particles **122** in layer **134** to obtain a temperature sufficient to enter a molten state. As layer **134** transitions to a solid amorphous state to an implementable state (e.g., a ceramic-glass state), layer **134** may receive indirect energy from one or more lasers directing energy to other layers formed on layer **134**. According to various embodiments, integrated end effector **112** may alternate between (1.) depositing and compressing a layer, which may be formed on another layer in operation **120** and (2.) activating one or more lasers to transfer energy into a layer in operation **130**, whereby timing and temperature may be controlled by integrated end effector **120** to promote optimal crystallization.

[0027] In some embodiments, integrated end effector **112** may be configured to perform laser-based vitreous material transform (or “VMX”) to form glassy ceramic or equivalents thereof. In some examples, one or more lasers may be configured to deliver energy for absorption by particulate to increase temperatures of, for example, lunar regolith to 2,000 degrees Celsius. In some examples, one or more lasers may provide temperatures in a range of 800 to 1,600 degrees Celsius. Further, integrated end effector **112** and lasers of power unit **136** may be configured to direct energy through a space in a vacuum, whereby the space (i.e., distance between one or more lasers and workpiece, such as source particulate **122** in a layer) is unenclosed and without enclosed walls, objects, or structures, such as a chamber. Integrated end effector **112** and one or more lasers are configured to generate sub-structures (e.g., of ceramic-glass) with which to build upon at vacuum pressures from atmospheric pressures (e.g., 760 Torr) to 10.sup.−3 Torr. In some examples, integrated end effector **112** and one or more lasers may be configured to operate in pressures from atmospheric to 10.sup.−8 Torr to 10.sup.−10 Torr depending, for example, on lunar temperatures and radiant sunlight heating.

[0028] As described, integrated end effector **112** is adaptable to form sub-structures using with particulates having a wide variety of characteristics and properties (and sometimes unknown) by, for example, adapting levels of laser energy (and other laser characteristics like frequency characteristics) in a vacuum. By doing so, integrated end effector **112** can adapt laser-generated temperatures to control a rate of crystallization of layers of source particulate **122** to form optimal implementable sub-structures (e.g., ceramic-class sub-structures). Hence, resultant layers, sub-structures, and structures may have relatively low or negligible coefficients of thermal expansion ("CTE"), or linear CTE, in accordance with ASTM standards (e.g., ASTM standard E228) of West Conshohocken, Pennsylvania. Relatively low or negligible CTE values indicate robustness under thermal conditions, such on a lunar surface as temperature may fluctuate +/−300 degrees Celsius. Additionally, integrated end effector **112** is configured to filter or sort particulate **114** of imprecisely known qualities to enhance abilities to form sub-structures using laser energy unenclosed in a vacuum. In various examples, the term "sub-structure" may refer to a unit of a structure or may be used interchangeably with the term "structure." Also, in some examples, the term "layer" may, as a sub-structure, be referred to as a structure. The terms layer, sub-structure, and structure may be interchangeable. Any of the structures and/or functionalities described herein are not limited to a specific environment and are applicable terrestrially as well as non-terrestrially.

[0029] FIG. **2** is a diagram depicting an example of an integrated end effector coupled to a robotic articulator, according to at least one example. Diagram **200** includes an integrated end effector **112** coupled to a robotic articulator **202**, which, in turn is coupled to a base **210**. As shown, robotic articulator **202** may include any number of rotatable joints **204** to provide, for example, 4 to 8 degrees of freedom. In some cases, robotic articulator may implement six (6) joints **204**. Robotic articulator **202** may provide integrated end effector **112** with an ability to travel or traverse distances at any radius about base **210**. Further, robotic articular **202** can manipulate integrated end effector **112** to position or orient its scoop (or any other component including its lasers) in any position or orientation in frame of reference **220**. In some cases, robotic articulator **202** may include a dust jacket (not shown) and umbilical cables and lines, including power and communications for integrated end effector **112**. According to one example, base **210** may be a lander regardless of whether being stationary or mobile. Base **210** may also include logic **212** with which to provide processing capabilities for controlling integrated end effector **112** as a function of sensor data received from integrated end effector **112**. Logic **212** includes hardware or software, or any combination thereof, to execute programmable instructions to operate integrated end effector **112**. Also, logic **212** may include a transceiver to communicate over long distances (e.g., between earth and moon). Note, however, integrated end effector **112** may include logic configured to implement some of all functions provided by logic **212**.

[0030] FIG. **3** is a perspective view of an example of an integrated end effector, according to some embodiments. Diagram **300** includes an integrated end effector **312** including a scoop **316** associated with a filter **324**, a compression surface unit **333**, one or more lasers **340**, and an interface **341** to couple mechanically and electrically to a robotic articulator, any of which may be structurally and/or functionally of similarly referenced elements described above. Interface **341** enables a robotic articulator to articulate integrated end effector **312** in any number of degrees of freedom (e.g., 6 or more DOF).

[0031] In a first function performed by integrated end effector **312**, as described in FIG. **1**, scoop **316** may be configured to collect and extract raw particulate, such as lunar regolith. Scoop **316** is shown to be coupled to a filtering motor **332**, which may be configured to impart mechanical energy to modify a spatial position of scoop **316** relative to other portions of the integrated end effector **312**. As such, filtering motor **332** may urge scooped particulate toward filter **324**. In some examples, filtering motor **332** may be implemented as a vibratory feed motor. Note that filter **324** may be configured to filter, discharge, or select one or more subsets of source particulates. In some cases, filter **324** may be configurable to select characteristics with which to separate particulates, or filter **324** may include multiple sub-filters each tuned to filter based on certain characteristics. For example, filter **324** may be configured to adjust filtering based on particulate size so that filter **324** may adjust filtering sizes from **2** mm to sub-millimeter sizes. Filter **324** may filter particulate based on other characteristics, such as a detected type of mineral fragment.

[0032] During filtering, a sensor in a group of sensor(s) **304** may be implemented as an image capture device (e.g., a camera) to detect a relative positioning of particulate in scoop **316** and generate a sensor data signal identifying the positioning. In response, a robotic articulator may cause scoop **316** to be oriented more positively in the Z-axis of frame of reference **399** with a rotation along the X-axis to funnel extracted particulate toward filter **324**. Integrated end effector **312** may include sensor **325**, which may be any type of sensor. In one example, sensor **325** may be an acoustic sensor configured to detect flow of filtered particulate to determine whether filtering is substantially completed. Scoop **316** may also include a hardness tool **326** to determine relative degrees of hardness of an object at a worksite external to integrated end effector **312**. Integrated end effector **312** is shown to include a light **302** to provide illumination or enhancements for image recognition for sensors **304** to detect a portion of a worksite from which particulate, such as regolith, may be collected. Sensors **304** may be activated to scan a worksite to identify an object or objects that ought to be removed. For example, large obstructions relative to filtering or weathered regolith layers may be found present at a worksite. Therefore, scoop **316** may be implemented to remove objects or undesirable particulate to reduce impediments when extracting particulate. An optional mineral composition sensor **380** may be included to detect a type or an amount of a certain minerals and can generate a sensor signal indicating information regarding a detected mineral. In some cases, mineral composition sensor **380** may be implemented on base **210** of FIG. **2**.

[0033] Referring back to FIG. **3**, in a second function performed by integrated end effector **312**, as described in FIG. **1**, scoop **316** may be configured to collect source particulate (e.g., targeted regolith) that has been filtered through filter **324**. In a third function performed by integrated end effector **312**, as described in FIG. **1**, scoop **316** may be configured to dispense or deposit source particulate in an alignment for forming a layer that is to be implemented as a sub-structure of a structure. In a fourth function, as described in FIG. **1**, integrated end effector **312** may implement compression surface unit **333** to compress or tamp deposited source particulate to form a layer.

[0034] In a fifth function, integrated end effector **312** implements one or more other components to transition source particulate in layer **334** from a first solid state (e.g., as lunar regolith) to a molten state, and then to a second solid state (e.g., as an annealed solid). Thereafter, nucleation may be controlled by integrated end effector **312** to transform layer **334** through optimal crystallization based on controlled temperatures and controlled time to produce a layer **134** as a sub-structure. For example, upon determining a layer of filtered particulate has been deposited, integrated end effector **312** may be oriented in frame of refence **399** to process that layer of filtered particulate (e.g., filter regolith) to form a sub-structure (e.g., a ceramic-glass structure) upon which a structure may be constructed.

[0035] As shown in diagram **300**, integrated end effector **312** includes a thermal image sensor **346**, a process image sensor **348**, a profilometer **330**, and a lens carousel **342**, as well as the aforementioned lasers **340**. While any number of lasers **340** may be implemented, diagram **300** depicts two lasers **340** that apply energy to layer **334** to cause source particulate (e.g., regolith) to “melt” and crystalize and form an implementable state (e.g., a ceramic-glass sub-structure). In some examples, lasers **340** may provide equivalent or varied amounts of power from 180 watts to 1000 watts, or greater (e.g., 8000 watts). Lasers **340** may provide laser energy at wavelengths in the infrared range, such as in the range of approximately 1064 nm, or any other ranges of wavelengths.

Laser **340** may include a laser diode array and integrated optics, or any other laser energy source.

[0036] A lens carousel **342** includes a transparent protective lens through which laser light may pass and is designed to protect laser **340** from receiving heated (and potentially damaging) particulate that may eject (e.g., as ejecta) from a surface of layer **334** in the lasing process. Lens carousel **342** may include a motor configured to rotate a lens should lasing efficiency decrease due to occlusions. Process image sensor **348** may be implemented to determine alignment and position of laser energy **388** relative to the surface of layer **334**. Also, process image sensor **348** can provide sensor data representing feedback to adjust position of lasers **340** of integrated end effector **312** to bring the lasers **340** into alignment. Profilometer **330** is configured to scan the surface of layer **334** to identify non-conforming dimensions, such as whether a hole or a variance in height or depth may exist. If an abnormality is detected, integrated end effector **312** may be configured to remedy the abnormality (e.g., generating sensor feedback to instruct integrated end effector **312** to repair a non-conforming hole).

[0037] Integrated end effector **312** is shown to include a thermal image sensor **346** configured to monitor characteristics of thermal image **349** representing laser energy **388** impacting a surface of layer **334**, whereby thermal image sensor **346** may be configured to detect one or more ranges of wavelengths (e.g., infra-red or any other ranges of wavelengths). Thermal image **349** generated by thermal image sensor **346** may indicate temperature values and gradients local to the lasing process. In some instances, composition of source particulate (e.g., regolith) in layer **334** may generate a thermal image **349** that may indicate that more or less laser energy may be applicable, and, if so, thermal image sensor **346** may generate a sensor data signal **370**. Responsive to sensor data signal **370**, logic (e.g., logic **212** of FIG. **2**) may generate control data **372** to modify functionality of lasers **340**, such as adapting power levels, modifying wavelengths, etc. Therefore, sensor data from thermal image sensor **346** may be used to modify or adapt temperatures at the surface of layer **334**, which, in turn, assists in controlling nucleation and crystallization of source particulate as it forms into, for example, a ceramic-glass sub-structure. Controlling temperatures at a surface of layer **334** enables an ability to achieve enhanced quality of the composition of layer **334** post-process.

[0038] FIG. **4** illustrates an example of a thermal profile for a layer of particulate during application of laser energy, according to some examples. Diagram **400** depicts a thermal profile **401** or temperature schedule against which laser energy absorption and temperatures at a source particulate may be monitored and controlled to optimize nucleation and crystallization of the base materials to optimize formation of an implementable sub-structure (e.g., a ceramic-glass sub-structure). In some examples, diagram **400** depicts a thermal profile **401** for a layer undergoing application of direct laser energy with subsequent exposure to indirect laser energy as other layers of particulate are deposited, compressed, and subjected to an amount of laser energy as experienced by the layer associated with thermal profile **401**. Thermal profile **401** may be implemented as data representing laser absorption energy (temperature) for a source particulate as a function of time.

[0039] Thermal profile **401** includes presentation of raw particulate **410** to a process of receiving laser energy in accordance with processes described herein. For example, a first layer of source particulate associated with thermal profile **401** has been filtered, deposited, and compressed and is receiving laser energy during a time shown as a first layer deposited **430**. As shown, the temperature of the first layer increases under first level laser power **412**, which is applied within time **470**. Laser energy application may cease or be reduced at a point in time during time **470**, with source particulate of the first layer transitioning to a molten state at **420**. At time **470**, the layer first transitions to a solid state **422** at which source particulate is annealed as an amorphous glass with at least some degrees of homogeneity.

[0040] A second layer is deposited and compressed over the first layer during time **432** and the second layer may receive a first level laser power **412** (unless integrated end effector adjusts the power level since the first layer). The first layer receives the laser energy as second level laser power **414** as the second layer may be translucent. At the time shown on thermal profile **401**, the first layer is under a process of crystallization **440**. Advantageously, at least in the example shown, the received laser energy of second level laser **414** promotes homogeneity and crystallization. Also, the second layer deposited on the first layer may provide insulative effects for the first layer, which, in turn, enhances crystallization. In some cases, the thermal energy of the first layer received during time **470** may transfer to the second layer, thereby requiring less application of laser power to the second layer during time **472**.

[0041] A third layer is deposited and compressed over the second and the first layers during time **434**. Also, the third layer may receive a first level laser power **412** (unless integrated end effector adjusts the power level since the first layer). As the third and second layers may be translucent, the first layer at an intermediate state may receive a third level of laser power **416** indirectly, which promotes homogeneity and crystallization as described for the second layer. Approximately at the end of time **474**, the first layer may transition into an implementable state **426**. In various examples, the first layer is formed as a ceramic-glass structure suitable for implementation to additively construct structures, such as landing pads.

[0042] In view of thermal profile **401**, an integrated end effector including a thermal image sensor and one or more controllable lasers may be configured to adapt levels of laser energy applied to a subset of indigenous particulate to form structures in a vacuum in-situ. For example, a thermal image sensor may detect whether a temperature associated with first level laser power **412** may be lower or higher than expected due to a variance, for example, based on a type or quantity of source particulate (e.g., a type or quantity of regolith). As the variance may affect quality during crystallization **440**, output of one or more lasers may be adapted or calibrated to align temperatures with thermal profile **401** to optimize crystallization **440** in formation of a ceramic-glass sub-structure or any other sub-structure. Integrated end effector may also be configured to modify times **470**, **472**, and **474** to optimize crystallization.

[0043] Note that thermal profile **401** may be varied and is not limited to that shown in diagram **400**. For example, fewer or more applications of laser power at **412**, **414**, and **416** may be implemented, such as fourth level laser power application cycle. Also, in some examples, other thermal profiles **401** may be implemented at other temperatures and times based on a specific type of particulate (e.g., regolith) undergoing application of laser energy.

[0044] FIGS. **5**A and **5**B depict exemplary structures or sub-structures additively constructed, according to some examples. FIG. **5**A is a diagram **500** that depicts a structure or a sub-structure **500** formed using an integrated end effector in accordance with processes and techniques described herein. Layers **512**, **514**, **516**, and **518** (and possibly more) may be formed by: (1) extracting particulate, (2) filtering particulate, (3) depositing particulate, (4) compressing particulate, and (5) applying energy to particulate to change its state, as described above. Consider that layer **512** is the first layer described in FIG. **4** and may have a temperature ("temp_1") **530**, and layer **514** is formed thereupon. Layer **514** may be associated with temperature ("temp_2") **532**, which may be higher than temperature ("temp_1") **530** as layer **514** receives less laser energy while transferring thermal energy to layer **514**. Similarly, as layers **516** and **518** are formed, respective temperature ("temp_3") **534** and temperature ("temp_4") **536** may have thermal interactions equivalent to layers **512** and **514**. As shown in diagram **500**, a structure/sub-structure **510** is formed with a composition of ceramic-glass, at least in some cases. However, in accordance with the systems and processes described herein, structure/sub-structure **510** may be composed of any material and is not limited to ceramic-glass.

[0045] FIG. **5**B is a diagram of another example of a structure or sub-structure that may be additively constructed. Diagram **550** depicts a structure or sub-structure **561***a* that may be constructed with layers **562**, **564**, **566**, and **568** in which each layer may not be monolithic. Specifically, layers **562**, **564**, **566**, and **568** are constructed additively as forms having a hollow core **560**. Further to diagram **550**, a scoop **574** may be configured to deposit particulate **572** in hollow core **560**, whereby particulate **572** may include source particulate (e.g., filtered regolith). But particulate **572** need not be source particulate (i.e., need not be filtered regolith) as in this case particulate **572** may provide load-bearing structural support and need not be subjected to a lasing process. An integrated end effector may be configured to compress or tamp particulate **572** deposited in hollow core **560**.

[0046] One or more top layers **570** may be formed similar to layers **512** to **518**

[0047] on top of structure or sub-structure **561***a*. Further, structure or sub-structure **561***a* may be formed as part of grid-like structure, with a portion of a neighboring structure or sub-structure **561***b* shown. Note that a structure, like a road, make be composed of a grid of multiple implementations of structures or sub-structures **561***a* and **561***b*. Further, structure or sub-structure **561***a* need be limited to a rectangular “brick-like” shape but may formed with any shape or form. For example, structures or sub-structures **561***a* and **561***b* may be formed as depicted in a top view of sub-structures **590**.

[0048] FIG. **6** depicts an example flow with which to form a structure or sub-structure, according to some embodiments. Flow **600** initiates at **602**, a portion of a worksite from which to collect particulate may be identified via one or more sensors. At **604**, a scoop structure may be activated to extract particulate from a portion of a worksite. At **606**, extracted particulate may be filtered to generate source particulate. At **608**, a first portion of a source particulate may be dispensed as a first layer. At **610**, a directed energy of a first level may be applied to a first layer. At **612**, a first portion of a source particulate in a first layer may transition to a molten state based on the directed energy applied thereto.

[0049] At **614**, a first solid layer is formed from a first layer that was in a molten state. At **616**, multiple other solid layers may be formed upon a first solid layer to additively construct a 3D printed structurer.

[0050] FIG. **7** depicts another example flow with which to form multiple structures or sub-structures, according to some embodiments. Flow **700** initiates at **702**, a scoop structure may receive multiple portions of particulate from a soil at a worksite. For example, a scoop structure may repeatedly scoop up particulate form a sufficient amount of source material. In some examples, source material may include optimal types of regolith. At **704**, a filter to receive multiple portions of particulate (e.g., over time) may be implemented to select separate multiple subsets of source particulates (e.g., over time) from discardable particulate. At **706**, a filtering motor may be activated to urge discharge of a multiple subsets of source particulates, whereby each discharge may be sequential. At **708**, multiple subsets of source particulates may be deposited as multiple layers, wherein each subset of source particulates may be deposited on each other in accordance with additive construction. At **710**, multiple layers may each be compressed individually or any number of multiples. At **712**, one or more power units may be activated to direct energy to one of multiple layers to transform into a first molten state. At **714**, one or more power units may be activated to direct energy to another one of multiple layers to transform into a second molten state. At **716**, a molten state of one of the multiple layers may be formed upon another of the multiple layers that is in a solid state.

[0051] FIG. **8** illustrates an exemplary application architecture for controlling in-situ application of adaptive levels of energy applied to a subset of indigenous particulate to form structures in a vacuum, according to some examples. Diagram **800** is shown to include an application **810** including modules configured to provide functionalities based on at least sensor data **802** received from an integrated end effector **850**, and the modules are further configured to generate control signal data **804** to control operation of integrated end effector **840**. Structurally, in some examples, application **810**, and the elements shown and described may be implemented as hardware, software, firmware, logic-specific circuitry, or as a combination thereof, without restriction or limitation to any particular implementation environment, 3D printing manufacturing process (or any other suitable manufacturing process), or configuration to form structure like shelters, houses, buildings, roads, hangers, landing pads, blast shields, etc. Modules implemented in application **810** with substantially similarly reference numbers or names may function similar to the other elements shown and described herein, including FIG. **1** and any other figure.

[0052] As shown in diagram **800**, application **810** may include a 3D additive construction manager **812**, a sensor data processor module **820**, a scoop orientation module **822**, a filter module **824**, a dispersal module **826**, a compression module **828**, a radio transceiver module **830**, a laser control module **832**, which may include thermal profile module **833**, a profilometer module **834**, and a thermal image module **836**, among others.

[0053] 3D additive construction manager **812** may be configured to control and coordinate operation and functionalities of other modules to manage operation of an integrated end effector, whereby 3D additive construction manager **812** may manage communications and transmissions of control signal data **804** generated by other modules. Further, 3D additive construction manager **812** may include logic configured to access data representing source code to generate one or more structures (e.g., data files in G-Code or the like), and may further include logic configured to control operation of a robotic actuator to position and orient an integrated end effector to perform functions described herein.

[0054] Sensor data processor module **820** may be configured to receive a variety of subsets of sensor data **802** from any number of sensors, such as, but not limited to, one or more image capture devices (e.g., cameras) including a process image sensor, one or more thermal cameras, one or more profilometers, sensors related to one or more lasers (e.g., thermal data, etc.), sensors related to a filtering motor (e.g., vibratory frequency to confirm operational), acoustic sensors, sensors related to a hardness tool (e.g., a Schmidt hammer), sensors relating to a lens carousel (e.g., to confirm operation). Other sensor data may be received from inertial measurement units ("IMUs") that identify forces, angular rate of change, accelerations, rates of speed, position data relative to an integrated end effector, and the like for a robotic actuator. Additional sensor data from a robotic actuator may be received from light detection and range sensors ("Lidar"), acoustic sensors, ultrasonic sensors, radar, pressure sensors, gyros, and the like.

[0055] Scoop orientation module **822** may receive commands to position and orient scoop to extract particulate, filter particulate, deposit particulate, compress particulate, apply energy via lasers to a particulate to change its state, among other functionalities. Filter module **824** may be configured to initiate filtering by generating commands to an integrated end effector to manage operation of a filtering process. Dispersal module **826** may be configured to initiate deposition of source particulate in preparation to receive compression forces, which, by commanded by compression module **828**.

[0056] Radio transceiver module **830** may be configured to exchange radio communications wirelessly via radio data **803** and may be conduit between an integrated end effector and a remote location (e.g., Austin, TX). Radio data **803** may include executable instructions as code, sensor data, etc. Laser control module **832** may be configured to control operation of one or more lasers, such as modifying power, modifying wavelengths, etc. Laser control module **832** may also include a thermal profile module **833** configured to access data representing a thermal profile or a temperature schedule to monitor laser outputs and data from a thermal image camera. Profilometer module **834** may be configured to monitor and control a profilometer, as well as generating data representing issues with a profile or surface of a layer being formed. Thermal image module **836** may be configured to monitor and control a thermal image camera, as well as processing data from the thermal image camera to coordinate laser operation with laser control module **832**.

[0057] Note that each of the modules of application **810** may interact electronically with each other to correlate and/or combine functionalities to provide for material deposition using indigenous particulate. Further, any module may communicate internally or externally with other applications or other computing platforms via, for example, an application programming interface ("API").

[0058] Any of the described modules of FIG. **8** or any other processes described herein in relation to other figures may be implemented as software, hardware, firmware, circuitry, or a combination thereof firmware, logic-specific circuitry, or as a combination thereof, without restriction or limitation. Any of modules of FIG. **8** may be disposed, placed, distributed, or arranged in a base, such as base **210** of FIG. **2**, or any module may be distributed at other portions of a system other than in a base, such as in an integrated end effector.

[0059] If implemented as software, the described techniques may be implemented using various types of programming, development, scripting, or formatting languages, frameworks, syntax, applications, protocols, objects, or techniques, including, but not limited to, "G-Code," Python™, ASP, ASP.net, .Net framework, Ruby, Ruby on Rails, C, Objective C, C++, C #, Adobe® Integrated Runtime™ (Adobe® AIR™), ActionScript™, Flex™, Lingo™, Java™, JSON, Javascript™, Ajax, Perl, COBOL, Fortran, ADA, XML, MXML, HTML, DHTML, XHTML, HTTP, XMPP, PHP, and others, including SQL™, SPARQL™, Turtle™, etc., as well as any proprietary application and software provided or developed by ICON Technology, Inc., or the like. The above-described techniques may be varied and are not limited to the embodiments, examples, or descriptions provided.

[0060] FIG. **9** illustrates examples of various logic and computing platforms configured to provide various functionalities to components of a base unit, such as a lander of FIG. **2**, configured to provide functionalities described herein.

[0061] FIG. **9** illustrates examples of various computing platforms configured to provide various functionalities to components of a computing platform **900** configured to provide functionalities described herein. Computing platform **900** may be used to implement computer programs, applications, methods, processes, algorithms, or other software, as well as any hardware implementation thereof, to perform the above-described techniques.

[0062] In some cases, computing platform **900** or any portion (e.g., any structural or functional portion) can be disposed or located in any device, such as a computing device **990***a*, mobile computing device **990***b*, and/or a processing circuit in association with initiating any of the functionalities described herein, via user interfaces and user interface elements, according to various examples.

[0063] Computing platform **900** includes a bus **902** or other communication mechanism for communicating information, which interconnects subsystems and devices, such as processor **904**, system memory **906** (e.g., RAM, etc.), storage device **908** (e.g., ROM, etc.), an in-memory cache (which may be implemented in RAM **906** or other portions of computing platform **900**), a communication interface **913** (e.g., an Ethernet or wireless controller, a Bluetooth controller, NFC logic, etc.) to facilitate communications via a port on communication link **921** to communicate, for example, with a computing device, including mobile computing and/or communication devices with processors, including database devices (e.g., storage devices configured to store relational data, structured data, unstructured data, and graph data or atomized datasets, including, but not limited to triple stores, etc.). Processor **904** can be implemented as one or more graphics processing units ("GPUs"), as one or more central processing units ("CPUs"), such as those manufactured by Intel® Corporation, or as one or more virtual processors, as well as any combination of CPUs and virtual processors. Or, a processor may include a Tensor Processing Unit ("TPU"), or equivalent. Computing platform **900** exchanges data representing inputs and outputs via input-and-output devices **901**, including, but not limited to, keyboards, mice, audio inputs (e.g., speech-to-text driven devices), user interfaces, displays, monitors, cursors, touch-sensitive displays, touch-sensitive inputs and outputs (e.g., touch pads), LCD or LED displays, and other I/O-related devices.

[0064] Note that in some examples, input-and-output devices **901** may be implemented as, or otherwise substituted with, a user interface in a computing device associated with, for example, a user account identifier in accordance with the various examples described herein.

[0065] According to some examples, computing platform **900** performs specific operations by processor **904** executing one or more sequences of one or more instructions stored in system memory **906**, and computing platform **900** can be implemented in a client-server arrangement, peer-to-peer arrangement, or as any mobile computing device, including smart phones and the like. Such instructions or data may be read into system memory **906** from another computer readable medium, such as storage device **908**. In some examples, hard-wired circuitry may be used in place of or in combination with software instructions for implementation. Instructions may be embedded in software or firmware. The term “computer readable medium” refers to any tangible medium that participates in providing instructions to processor **904** for execution. Such a medium may take many forms, including but not limited to, non-volatile media and volatile media. Non-volatile media includes, for example, optical or magnetic disks and the like. Volatile media includes dynamic memory, such as system memory **906**.

[0066] Known forms of computer readable media includes, for example, floppy disk, flexible disk, hard disk, magnetic tape, any other magnetic medium, CD-ROM, any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, RAM, PROM, EPROM, FLASH-EPROM, any other memory chip or cartridge, or any other medium from which a computer can access data. Instructions may further be transmitted or received using a transmission medium. The term “transmission medium” may include any tangible or intangible medium that is capable of storing, encoding, or carrying instructions for execution by the machine, and includes digital or analog communications signals or other intangible medium to facilitate communication of such instructions. Transmission media includes coaxial cables, copper wire, and fiber optics, including wires that comprise bus **902** for transmitting a computer data signal.

[0067] In some examples, execution of the sequences of instructions may be performed by computing platform **900**. According to some examples, computing platform **1500** can be coupled by communication link **921** (e.g., a wired network, such as LAN, PSTN, or any wireless network, including WiFi of various standards and protocols, Bluetooth®, NFC, Zig-Bee, etc.) to any other processor to perform the sequence of instructions in coordination with (or asynchronous to) one another. Computing platform **900** may transmit and receive messages, data, and instructions, including program code (e.g., application code) through communication link **921** and communication interface **913**. Received program code may be executed by processor **904** as it is received, and/or stored in memory **906** or other non-volatile storage for later execution.

[0068] In the example shown, system memory **906** can include various modules that include executable instructions to implement functionalities described herein. System memory **906** may include an operating system (“O/S”) **932**, as well as an application **936** and/or logic module(s) **959**. In the example shown in FIG. **9**, system memory **906** may include any number of modules **959**, any of which, or one or more portions of which, can be configured to facilitate any one or more components of a computing system (e.g., a client computing system, a server computing system, etc.) by implementing one or more functions described herein.

[0069] The structures and/or functions of any of the above-described features can be implemented in software, hardware, firmware, circuitry, or a combination thereof. Note that the structures and constituent elements above, as well as their functionality, may be aggregated with one or more other structures or elements. Alternatively, the elements and their functionality may be subdivided into constituent sub-elements, if any. As software, the above-described techniques may be implemented using various types of programming or formatting languages, frameworks, syntax, applications, protocols, objects, or techniques. These can be varied and are not limited to the examples or descriptions provided.

[0070] In some embodiments, modules **959** of FIG. **9**, or one or more of their components, or any process or device described herein, can be in communication (e.g., wired or wirelessly) with a mobile device, such as a mobile phone or computing device, or can be disposed therein.

[0071] In some cases, a mobile device, or any networked computing device (not shown) in communication with one or more modules **959** or one or more of its/their components (or any process or device described herein), can provide at least some of the structures and/or functions of any of the features described herein. As depicted in the above-described figures, the structures and/or functions of any of the above-described features can be implemented in software, hardware, firmware, circuitry, or any combination thereof. Note that the structures and constituent elements above, as well as their functionality, may be aggregated or combined with one or more other structures or elements. Alternatively, the elements and their functionality may be subdivided into constituent sub-elements, if any. As software, at least some of the above-described techniques may be implemented using various types of programming or formatting languages, frameworks, syntax, applications, protocols, objects, or techniques. For example, at least one of the elements depicted in any of the figures can represent one or more algorithms. Or, at least one of the elements can represent a portion of logic including a portion of hardware configured to provide constituent structures and/or functionalities.

[0072] For example, modules **959** or one or more of its/their components, or any process or device described herein, can be implemented in one or more computing devices (i.e., any mobile computing device, such as a wearable device, such as a hat or headband, or mobile phone, whether worn or carried) that include one or more processors configured to execute one or more algorithms in memory. Thus, at least some of the elements in the above-described figures can represent one or more algorithms. Or, at least one of the elements can represent a portion of logic including a portion of hardware configured to provide constituent structures and/or functionalities. These can be varied and are not limited to the examples or descriptions provided.

[0073] As hardware and/or firmware, the above-described structures and techniques can be implemented using various types of programming or integrated circuit design languages, including hardware description languages, such as any register transfer language ("RTL") configured to design field-programmable gate arrays ("FPGAs"), application-specific integrated circuits ("ASICs"), multi-chip modules, or any other type of integrated circuit. For example, modules **959** or one or more of its/their components, or any process or device described herein, can be implemented in one or more computing devices that include one or more circuits. Thus, at least one of the elements in the above-described figures can represent one or more components of hardware. Or, at least one of the elements can represent a portion of logic including a portion of a circuit configured to provide constituent structures and/or functionalities.

[0074] According to some embodiments, the term "circuit" can refer, for example, to any system including several components through which current flows to perform one or more functions, the components including discrete and complex components. Examples of discrete components include transistors, resistors, capacitors, inductors, diodes, and the like, and examples of complex components include memory, processors, analog circuits, digital circuits, and the like, including field-programmable gate arrays ("FPGAs"), application-specific integrated circuits ("ASICs"). Therefore, a circuit can include a system of electronic components and logic components (e.g., logic configured to execute instructions, such that a group of executable instructions of an algorithm, for example, and, thus, is a component of a circuit). According to some embodiments, the term "module" can refer, for example, to an algorithm or a portion thereof, and/or logic implemented in either hardware circuitry or software, or a combination thereof (i.e., a module can be implemented as a circuit). In some embodiments, algorithms and/or the memory in which the algorithms are stored are "components" of a circuit. Thus, the term "circuit" can also refer, for example, to a system of components, including algorithms. These can be varied and are not limited to the examples or descriptions provided.

[0075] Although the foregoing examples have been described in some detail for purposes of clarity of understanding, the above-described inventive techniques are not limited to the details provided. There are many alternative ways of implementing the above-described invention techniques. The disclosed examples are illustrative and not restrictive.

Claims

1. A method comprising: identifying via one or more sensors at an integrated end effector a portion of a worksite from which to collect particulate; causing a scoop structure to extract particulate from the portion of the worksite to form extracted particulate; filtering the extracted particulate to generate source particulate; dispensing a first portion of the source particulate at a target portion of the worksite to form a first layer; applying a directed energy at a first level to the first layer to transition to a molten state; and forming a first solid layer from the first layer in the molten state with which to form a three-dimensional (“3D”) structure.
2. The method of claim 1 wherein the particulate includes at least a portion of regolith particles and the source particulate includes at least a portion of source regolith.
3. The method of claim 1 wherein applying the directed energy further comprises: activating one or more lasers to cause the first portion of source particulate to absorb laser energy and increase a temperature to a first temperature.
4. The method of claim 1 wherein applying the directed energy further comprises: activating one or more lasers to direct laser energy through a space in a vacuum.
5. The method of claim 4 wherein the space is unenclosed.
6. The method of claim 1 wherein dispensing the portion of the first source particulate at the target portion of the worksite further comprises: compressing the first portion of the source particulate associated with the target portion of the worksite.
7. The method of claim 1 further comprising: dispensing a second portion of the source particulate upon the first solid layer at the target portion of the worksite to form a second layer.
8. The method of claim 7 further comprising: applying a second level of directed energy to the first layer to cause the first portion of the source particulate in the first layer to transition to a crystallization state.
9. The method of claim 7 further comprising: activating the one or more lasers to cause the second portion of source particulate in the second layer to absorb laser energy to increase a temperature to a second temperature.
10. The method of claim 1 further comprising: activating one or more sensors to scan the worksite to identify an object other than the particulate; and removing the object from the worksite.
11. A system comprising: an integrated end effector comprising: a scoop structure configured to receive multiple portions of particulate from a soil at a worksite; a filter coupled to the scoop structure and configured to receive the multiple portions of particulate to separate multiple subsets of source particulates from discardable particulates; a filtering motor coupled to the scoop structure and configured to modify a spatial position of the scoop structure relative to other portions of the integrated end effector to urge discharging the multiple subsets of source particulates; a compression surface unit configured to compress deposited layers of the multiple source particles in multiple layers; and one or more power units configured to direct energy the multiple layers to transform the multiple layers into multiple molten states.
12. The system of claim 11 wherein the integrated end effector is configured to form the compressed deposited layers multiple layers upon each other, wherein at least a subset of the multiple molten states is formed sequentially.
13. The system of claim 11 wherein the one or more power units comprises: one or more lasers configured to direct the energy a distance including a vacuum.
14. The system of claim 13 wherein the distance including the vacuum is unenclosed.
15. The system of claim 13 further comprising; a thermal image sensor configured to detect directed energy absorption at one of the multiple layers and to generate data representing the directed energy absorption.
16. The system of claim 13 wherein the one or more lasers are configured to modify operating

characteristics responsive to data representing directed energy absorption.
17. The system of claim 11 wherein the filtering motor is a vibratory motor.
18. The system of claim 11 wherein the integrated end effector further comprises: a profilometer configured to detect surface characteristics of the first layer.
19. The system of claim 11 further comprising: a robotic articulator interface coupled to a robotic articulator configured to position and orient the integrated end effector spatially in one or more of an X-axis, a Y-axis, and a Z-axis.
20. A system comprising: a memory including executable instructions; and a processor, responsive to executing the instructions, is configured to: identify via one or more sensors at an integrated end effector a portion of a worksite from which to collect particulate; cause a scoop structure to extract particulate from the portion of the worksite to form extracted particulate; filter the extracted particulate to generate source particulate; dispense a first portion of the source particulate at a target portion of the worksite to form a first layer; apply a directed energy at a first level to the first layer to transition to a molten state; and cause formation of a first solid base layer from the first layer in the molten state with which to form a three-dimensional (“3D”) structure.