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| United States Patent Application Publication | 20250265388 |
| Kind Code | A1 |
| Publication Date | August 21, 2025 |
| Inventor(s) | Ott; Eric Allen et al. |


## ADDITIVE MANUFACTURING SIMULATIONS

### Abstract


Methods of simulating additively manufacturing an object may include generating a simulated additively manufactured object based at least in part on a plurality of approximate consolidation domains that respectively correspond to a plurality of consolidation tracks determined from one or more digital representations of an additively manufactured object, and determining a predictive inference with respect to one or more material properties of the object to be additively manufactured based at least in part on the simulated additively manufactured object. Methods may include generating, for an object to be additively manufactured, a CAD file and/or a build file based at least in part on a simulated additively manufactured object and/or based at least in part on one or more predictive inferences with respect to one or more material properties of the object to be additively manufactured. An object may be additively manufactured based at least in part on a simulated additively manufactured object and/or a CAD file and/or the build file corresponding thereto.



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**Family ID:** **1000008586589**

**Appl. No.:** **19/177036**

**Filed:** **April 11, 2025**


### Related U.S. Application Data

parent US continuation 17197767 20210310 parent-grant-document US 12299358 child US 19177036

## Publication Classification

**Int. Cl.:** **G06F30/20** (20200101); **B22F10/28** (20210101); **B22F10/38** (20210101); **B22F10/80** (20210101); **B29C64/153** (20170101); **B29C64/393** (20170101); **B33Y10/00** (20150101); **B33Y50/02** (20150101); **G06F30/17** (20200101); **G06F30/25** (20200101); **G06F111/08** (20200101); **G06F113/10** (20200101); **G06F119/18** (20200101)

**U.S. Cl.:**

CPC **G06F30/20** (20200101); **B22F10/38** (20210101); **B22F10/80** (20210101); **B29C64/393** (20170801); **B33Y10/00** (20141201); **B33Y50/02** (20141201); **G06F30/17** (20200101); **G06F30/25** (20200101); B22F10/28 (20210101); B29C64/153 (20170801); G06F2111/08 (20200101); G06F2113/10 (20200101); G06F2119/18 (20200101)

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## Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation application of U.S. application Ser. No. 17/197,767 filed Mar. 10, 2021, which is hereby incorporated by reference in its entirety.

FIELD
[0002] The present disclosure generally pertains to systems and methods for additively manufacturing of three dimensional objects, as well as systems and methods for designing three-dimensional objects to be additively manufactured.
BACKGROUND
[0003] Additive manufacturing technology may be utilized to manufacture three dimensional objects. An object that is intended to be additively manufactured must first be designed before the object can be additively manufactured. Design processes that yield three-dimensional objects meeting quality and or productivity parameters can be complex and time consuming.
[0004] Accordingly, there exists a need for improved systems and methods of additively manufacturing three-dimensional objects, including improved systems and methods of designing three-dimensional objects to be additively manufactured.
BRIEF DESCRIPTION
[0005] Aspects and advantages will be set forth in part in the following description, or may be apparent from the description, or may be learned through practicing the presently disclosed subject matter.
[0006] In one aspect, the present disclosure embraces methods of simulating additively manufacturing a three-dimensional object. An exemplary method may include generating a simulated additively manufactured three-dimensional object based at least in part on a plurality of approximate consolidation domains. The plurality of approximate consolidation domains may respectively correspond to a plurality of consolidation tracks determined from one or more digital representations of an additively manufactured three-dimensional object. An exemplary method may additionally or alternatively include determining a predictive inference with respect to one or more material properties of a three-dimensional object to be additively manufactured based at least in part on the simulated additively manufactured three-dimensional object.
[0007] In another aspect, the present disclosure embraces methods of designing an additively-manufactured three-dimensional object. An exemplary method may include generating a CAD file and/or a build file for a three-dimensional object to be additively manufactured. The CAD file and/or the build file may be generated based at least in part on a simulated additively manufactured

three-dimensional object and/or based at least in part on one or more predictive inferences with respect to one or more material properties of the three-dimensional object to be additively manufactured. The three-dimensional object may be additively manufactured based at least in part on the CAD file and/or the build file.

[0008] In yet another aspect, the present disclosure embraces methods of additively manufacturing a three-dimensional object. An exemplary method may include generating a simulated additively manufactured three-dimensional object based at least in part on a plurality of approximate consolidation domains. The plurality of approximate consolidation domains may respectively correspond to a plurality of consolidation tracks determined from one or more digital representations of an additively manufactured three-dimensional object. The three-dimensional object may be additively manufactured based at least in part on the simulated additively manufactured three-dimensional object.

[0009] In still another aspect, the present disclosure embraces computer-readable media. Exemplary computer-readable medium may include computer-executable instructions, which when executed by a processor, cause the processor to perform a method in accordance with the present disclosure, including, for example, a method of simulating additively manufacturing a three-dimensional object, a method of designing an additively-manufactured three-dimensional object, and/or a method of additively manufacturing a three-dimensional object.

[0010] These and other features, aspects and advantages will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate exemplary embodiments and, together with the description, serve to explain certain principles of the presently disclosed subject matter.

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## Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] A full and enabling disclosure, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended Figures, in which:

[0012] FIG. **1** schematically depicts an exemplary additive manufacturing system;

[0013] FIG. **2** schematically depicts an enlarged, cross-sectional view of an exemplary additively manufactured three-dimensional object;

[0014] FIGS. **3**A-**3**C schematically depict an exemplary top cross-sectional view, a longitudinal cross-sectional view, and a transverse cross-sectional view, of a respective consolidation tracks formed by an energy beam irradiating a bed of build material;

[0015] FIGS. **4**A-**4**C schematically depict an exemplary top cross-section, a longitudinal cross-section, and a lateral cross-section, of a respective approximate consolidation domain corresponding to the respective consolidation tracks depicted in FIGS. **3**A-**3**C;

[0016] FIG. **5** schematically depicts a plurality of top cross-sectional views of exemplary consolidation tracks formed by irradiation with respectively different irradiation parameter values, overlain by an approximate consolidation domain corresponding of the respective consolidation track;

[0017] FIGS. **6**A-**6**C schematically depict an exemplary probability map of a top cross-section, a longitudinal cross-section, and a lateral cross-section, respectively, of an approximate consolidation domain corresponding to a consolidation track formed by irradiation with given irradiation parameter values;

[0018] FIGS. **7**A-**7**C schematically depict an exemplary probability distribution of a top cross-sectional dimension, a longitudinal cross-sectional dimension, and a lateral cross-sectional

dimension, respectively, corresponding to a consolidation track formed by irradiation with given irradiation parameter values;
[0019] FIGS. **8**A-**8**C schematically depict cross-sectional view of exemplary simulated additively manufactured three-dimensional objects determined from an additive manufacturing simulation;
[0020] FIG. **8**D schematically depicts a cross-sectional view of an exemplary simulated additively manufactured three-dimensional object that exhibits simulated consolidation artifacts;
[0021] FIG. **8**E shows a graph depicting a number and percentage distribution of the void elements shown in the cross-sectional view of the simulated additively manufactured three-dimensional object of FIG. **8**D;
[0022] FIGS. **9**A-**9**D schematically depict exemplary configurations and arrangements of approximate consolidation domains for an additive manufacturing simulation;
[0023] FIGS. **10**A-**10**E schematically depict further exemplary configurations and arrangements of approximate consolidation domains for an additive manufacturing simulation;
[0024] FIG. **11** schematically depicts an exemplary control system, such as for an additive manufacturing simulation and/or for an additive manufacturing machine or system;
[0025] FIG. **12** schematically depicts an exemplary additive manufacturing simulation module, such as for simulating additively manufacturing a three-dimensional object;
[0026] FIG. **13** shows a flow chart depicting an exemplary method of simulating additively manufacturing a three-dimensional object;
[0027] FIG. **14** schematically depicts an exemplary object design module, such as for designing an additively-manufactured three-dimensional object;
[0028] FIG. **15** shows a flow chart depicting an exemplary method of designing an additively manufactured a three-dimensional object;
[0029] FIG. **16** schematically depicts an exemplary additive manufacturing module, such as for additively-manufacturing a three-dimensional object; and
[0030] FIG. **17** shows a flow chart depicting an exemplary method of additively manufacturing a three-dimensional object.
[0031] Repeat use of reference characters in the present specification and drawings is intended to represent the same or analogous features or elements of the present disclosure.

DETAILED DESCRIPTION

[0032] Reference now will be made in detail to exemplary embodiments of the presently disclosed subject matter, one or more examples of which are illustrated in the drawings. Each example is provided by way of explanation and should not be interpreted as limiting the present disclosure. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present disclosure without departing from the scope of the present disclosure. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the present disclosure covers such modifications and variations as come within the scope of the appended claims and their equivalents.
[0033] It is understood that terms “upstream” and “downstream” refer to the relative direction with respect to fluid flow in a fluid pathway. For example, “upstream” refers to the direction from which the fluid flows, and “downstream” refers to the direction to which the fluid flows. It is also understood that terms such as “top”, “bottom”, “outward”, “inward”, and the like are words of convenience and are not to be construed as limiting terms. As used herein, the terms “first”, “second”, and “third” may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components. The terms “a” and “an” do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.
[0034] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a

change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about,” “substantially,” and “approximately,” are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value, or the precision of the methods or machines for constructing or manufacturing the components and/or systems. For example, the approximating language may refer to being within a 10 percent margin.

[0035] Here and throughout the specification and claims, range limitations are combined and interchanged, such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise. For example, all ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other.

[0036] The presently disclosed subject matter pertains to additive manufacturing machines and/or related methods. As used herein, the term “additive manufacturing” refers generally to manufacturing technology in which components are manufactured in a layer-by-layer manner. An exemplary additive manufacturing machine may be configured to utilize any desired additive manufacturing technology. In an exemplary embodiment, the additive manufacturing machine may utilize an additive manufacturing technology that includes a powder bed technology, such as a direct metal laser melting (DMLM) technology, an electron beam melting (EBM) technology, an electron beam sintering (EBS) technology, a selective laser melting (SLM) technology, a directed metal laser sintering (DMLS) technology, or a selective laser sintering (SLS) technology. In an exemplary powder bed technology, thin layers of build material, such as powder material, are sequentially applied to a build plane and then selectively melted, fused, and/or sintered to one another in a layer-by-layer manner to form one or more three-dimensional objects. Additively manufactured objects are generally monolithic in nature, and may have a variety of integral sub-components.

[0037] Additionally or alternatively suitable additive manufacturing technologies include, for example, Binder Jet technology, Fused Deposition Modeling (FDM) technology, Direct Energy Deposition (DED) technology, Laser Engineered Net Shaping (LENS) technology, Laser Net Shape Manufacturing (LNSM) technology, Direct Metal Deposition (DMD) technology, Digital Light Processing (DLP) technology, Vat Polymerization (VP) technology, Sterolithography (SLA) technology, and other additive manufacturing technology that utilizes an energy beam.

[0038] Additive manufacturing technology may generally be described as enabling fabrication of complex objects by building objects point-by-point, layer-by-layer, typically in a vertical direction; however, other methods of fabrication are contemplated and within the scope of the present disclosure. For example, although the discussion herein refers to the addition of material to form successive layers, the presently disclosed subject matter may be practiced in connection or in combination with any additive manufacturing technology, including in connection or in combination with other manufacturing technology, such as layer-additive processes, layer-subtractive processes, or hybrid processes.

[0039] The additive manufacturing processes described herein may be used for forming components using any suitable material. For example, the material may be metal, ceramic, polymer, epoxy, photopolymer resin, plastic, concrete, or any other suitable material that may be in solid, liquid, powder, sheet material, wire, or any other suitable form. Each successive layer may be, for example, between about 10 μm and 200 μm, although the thickness may be selected based on any number of parameters and may be any suitable size according to alternative embodiments.

[0040] The present disclosure generally provides methods of simulating additively manufacturing a three-dimensional object. The simulation may utilize statistical inference to determine a plurality of approximate consolidation domains corresponding to consolidation tracks in an additively manufactured three-dimensional object formed by an energy beam when selectively irradiating regions of a build material. As used herein, the term “consolidation domain” refers to a domain of an additively manufactured three-dimensional object being subjected to consolidation by an energy beam at a given point along a consolidation track. The consolidation domain may be defined by a consolidation boundary. In some embodiments a consolidation domain may refer to a melt pool domain caused by the energy beam at the given point along the consolidation track, for example, in the case of a powder bed technology in which the energy beam melts build material such as with a DMLM process or an EBM process. The melt pool domain may be defined by a melt pool boundary corresponding to a transition from material that becomes molten to material that remains unmolten by the energy beam at the given point along the consolidation track. Additionally, or in the alternative, a consolidation domain may refer to a sintering domain caused by the energy beam at the given point along the consolidation track, for example, in the case of a powder bed technology in which the energy beam sinters build material, for example, generally without melting the build material such as with an EBS process, a DMLS process, or an SLS process. The sintering domain may be defined by a sintering boundary corresponding to a transition from material that becomes sintered to material that remains unsintered by the energy beam at the given point along the consolidation track. In yet another embodiment, a consolidation domain may refer to a reaction domain caused by the energy beam at the given point along the consolidation track, for example, in the case of a Binder Jet process in which an energy beam causes a liquid binder material to undergo a reaction that solidifies adjacent binder material. The reaction domain may be defined by a reaction boundary corresponding to a transition from material that undergoes reaction to material that remains unreacted by the energy beam at the given point along the consolidation track. As used herein, the term "consolidation track" refers to a path along which a focal point of an energy beam propagates when selectively irradiating and thereby densifying regions of a build material.

[0041] Predictive inferences about one or more material properties of an object to be additively manufactured may be determined based at least in part on the simulation. For example, the simulation may include generating a simulated additively manufactured three-dimensional object, and predictive inferences about an object to be actually additively manufactured may be determined based at least in part on the simulated additively manufactured three dimensional object. CAD files and/or build files for an object to be additively manufactured may be generated based at least in part on the simulation and/or the predictive inferences. One or more three-dimensional objects may be additively manufactured based at least in part on the simulation and/or the predictive inferences, for example, using such CAD files and/or build files. Additionally, or in the alternative, one or more predictive inferences about material properties may be produced after additively manufacturing a three dimensional object, for example, by simulating one or more material properties and producing one or more predictive inferences about the three dimensional object and/or the material thereof.

[0042] Advantageously, the present disclosure may allow for additive manufacturing simulations that allow predictive inferences to be determined about three-dimensional objects without having to additively manufacture the three-dimensional objects. Improved object design process may be realized, including shortened lead times for designing three-dimensional objects and/or improved designs for three-dimensional objects. Additionally, or in the alternative, improved three-dimensional objects and/or improved additive manufacturing processes may be realized, including improved capabilities with respect to quality parameters and/or productivity parameters.

[0043] As used herein, the term "statistical inference" refers to using data analysis to deduce deterministic and/or probabilistic properties of one or more three-dimensional objects, including with respect to one or more material properties thereof. By way of example, a statistical inference may include a deterministic property such as a maximum, minimum, and/or range for a value of a material property of a three-dimensional object. Additionally, or in the alternative, a statistical inference may include a probabilistic property of such as a probability distribution for a value of a material property of a three-dimensional object.

[0044] As used herein, the term "predictive inference" refers to a statistical inference that pertains to the prediction of future observations based on past observations. By way of example, a predictive inference may include a deterministic property such as a maximum, minimum, and/or range for a value of a material property of a three-dimensional object. Additionally, or in the alternative, a predictive inference may include a probabilistic property of such as a probability distribution for a value of a material property of a three-dimensional object.

[0045] As used herein, the term “build plane” refers to a plane defined by a surface upon which an energy beam impinges during an additive manufacturing process. Generally, the surface of a powder bed defines the build plane; however, during irradiation of a respective layer of the powder bed, a previously irradiated portion of the respective layer may define a portion of the build plane, and/or prior to distributing build material, such as powder material, across a build module, a build plate that supports the powder bed generally defines the build plane. For processes that to not utilize a powder bed, the term “build plane” may refer to a surface plane upon which further additive deposition may be carried out when additively manufacturing a three-dimensional object.

[0046] Exemplary embodiments of the present disclosure will now be described in further detail. By way of example, FIG. **1** schematically depicts an exemplary additive manufacturing system **100** that utilizes a powder bed technology. The example provided with reference to FIG. **1** is provided by way of example only and is not intended to be limiting. Other embodiments that utilize a powder bed technology are also contemplated, as are other additive manufacturing technologies, all of which are within the scope of the present disclosure. As shown in FIG. **1**, the additive manufacturing system **100** may include one or more additive manufacturing machines **102**. The one or more additive manufacturing machines **102** may include a control system **104**. The control system may include componentry integrated as part of the additive manufacturing machine **102** and/or componentry that is provided separately from the additive manufacturing machine **102**. Various componentry of the control system **104** may be communicatively coupled to various componentry of the additive manufacturing machine **102**.

[0047] The control system **104** may be communicatively coupled with a management system **106** and/or a user interface **108**. The management system **106** may be configured to interact with the control system **104** in connection with enterprise-level operations pertaining to the additive manufacturing system **100**. Such enterprise level operations may include transmitting data from the management system **106** to the control system **104** and/or transmitting data from the control system **104** to the management system **106**. The user interface **108** may include one or more user input/output devices to allow a user to interact with the additive manufacturing system **100**.

[0048] As shown, an additive manufacturing machine **102** may include a build module **110** that includes a build chamber **112** within which an object or objects **114** may be additively manufactured. In some embodiments, an additive manufacturing machine **102** may include a powder module **116** and/or an overflow module **118**. The build module **110**, the powder module **116**, and/or the overflow module **118** may be provided in the form of modular containers configured to be installed into and removed from the additive manufacturing machine **102** such as in an assembly-line process. Additionally, or in the alternative, the build module **110**, the powder module **116**, and/or the overflow module **118** may define a fixed componentry of the additive manufacturing machine **102**.

[0049] The powder module **116** contains a supply of powder material **120** housed within a supply chamber **122**. The powder module **116** includes a powder piston **124** that elevates a powder floor **126** during operation of the additive manufacturing machine **102**. As the powder floor **126** elevates, a portion of the powder material **120** is forced out of the powder module **116**. A recoater **128** such as a blade or roller sequentially distributes thin layers of powder material **120** across a build plane **130** above the build module **110**. A build platform **132** supports the sequential layers of powder material **120** distributed across the build plane **130**.

[0050] The additive manufacturing machine **102** includes an energy beam system **134** configured to generate one or more energy beams, and to direct the respective energy beams onto the build plane **130** to selectively solidify respective portions of the powder bed **136** defining the build plane **130**.

The one or more energy beams may be a laser beam, an electron beam, a plasma beam, an electrical energy beam, an infrared beam, and so forth, as applicable to the respective additive manufacturing technology that may be utilized in a given embodiment. The one or more energy beams may respectively generate a consolidation domain **137** made up of at least partially molten powder material **120** as the energy beam passes across the powder bed **136**. In some embodiments, the consolidation domain **137** may be or may include a melt pool domain, such as in the case of a DMLM process or an EBM process. Additionally, or in the alternative, the consolidation domain **137** may be or include a sintering domain, such as in the case of an EBS process, a DMLS process, or an SLS process. In yet another embodiment, the consolidation domain **137** may be or include a reaction domain, such as in the case of a Binder Jet process. Referring to the exemplary embodiment shown in FIG. **1**, the one or more energy beams may move across the powder bed **136** according to a scan path defined by the control system **104**. As the consolidation domain **137** cools, the molten powder material solidifies to form a consolidation track in the powder bed **136**. Sequential consolidation track become integrally melted and/or fused with previously or concurrently formed consolidation track, such as from the current or previous layers of the powder bed **136**, to form the object **114**.

[0051] As the respective energy beams selectively melt or fuse the sequential layers of powder material **120** that define the powder bed **136**, the object **114** begins to take shape. Typically with a DMLM, EBM, or SLM system, the powder material **120** is fully melted, with respective layers being melted or re-melted with respective passes of the energy beams. Conversely, with DMLS or SLS systems, typically the layers of powder material **120** are sintered, fusing particles of powder material **120** to one another generally without reaching the melting point of the powder material **120**. The energy beam system **134** may include componentry integrated as part of the additive manufacturing machine **102** and/or componentry that is provided separately from the additive manufacturing machine **102**.

[0052] The energy beam system **134** may include one or more irradiation devices configured to generate a plurality of energy beams and to direct the energy beams upon the build plane **130**. The irradiation devices may respectively have an energy beam source, a galvo-scanner, and optical componentry configured to direct the energy beam onto the build plane **130**. For the embodiment shown in FIG. **1**, the energy beam system **134** includes a first irradiation device **138** and a second irradiation device **140**. In other embodiments, an energy beam system **134** may include three, four, six, eight, ten, or more irradiation devices. The plurality of irradiation devise may be configured to respectively generate one or more energy beams that are respectively scannable within a scan field incident upon at least a portion of the build plane **130**. For example, the first irradiation device **138** may generate a first energy beam **142** that is scannable within a first scan field **144** incident upon at least a first build plane region **146**. The second irradiation device **140** may generate a second energy beam **148** that is scannable within a second scan field **150** incident upon at least a second build plane region **152**. The first scan field **144** and the second scan field **150** may overlap such that the first build plane region **146** scannable by the first energy beam **142** overlaps with the second build plane region **152** scannable by the second energy beam **148**. The overlapping portion of the first build plane region **146** and the second build plane region **152** may sometimes be referred to as an interlace region **154**. Portions of the powder bed **136** to be irradiated within the interlace region **154** may be irradiated by the first energy beam **142** and/or the second energy beam **148** in accordance with the present disclosure.

[0053] To irradiate a layer of the powder bed **136**, the one or more irradiation devices (e.g., the first irradiation device **138** and the second irradiation device **140**) respectively direct the plurality of energy beams (e.g., the first energy beam **142** and the second energy beam **148**) across the respective portions of the build plane **130** (e.g., the first build plane region **146** and the second build plane region **152**) to melt or fuse the portions of the powder material **120** that are to become part of the object **114**. The first layer or series of layers of the powder bed **136** are typically melted or fused to the build platform **132**, and then sequential layers of the powder bed **136** are melted or fused to one another to additively manufacture the object **114**.

[0054] As sequential layers of the powder bed **136** are melted or fused to one another, a build piston **156** gradually lowers the build platform **132** to make room for the recoater **128** to distribute sequential layers of powder material **120**. As the build piston **156** gradually lowers and sequential layers of powdered material **120** are applied across the build plane **130**, the next sequential layer of powder material **120** defines the surface of the powder bed **136** coinciding with the build plane **130**. Sequential layers of the powder bed **136** may be selectively melted or fused until a completed object **114** has been additively manufactured.

[0055] In some embodiments, an additive manufacturing machine may utilize an overflow module **118** to capture excess powder material **120** in an overflow chamber **158**. The overflow module **118** may include an overflow piston **160** that gradually lowers to make room within the overflow chamber **158** for additional excess powder material **120**.

[0056] It will be appreciated that in some embodiments an additive manufacturing machine may not utilize a powder module **116** and/or an overflow module **118**, and that other systems may be provided for handling powder material **120**, including different powder supply systems and/or excess powder recapture systems. However, the subject matter of the present disclosure may be practiced with any suitable additive manufacturing machine without departing from the scope hereof.

[0057] Still referring to FIG. **1**, in some embodiments, an additive manufacturing machine **102** may include a monitoring system **162**. The monitoring system **162** may be configured to detect a monitoring beam (not shown) such as an infrared beam from a laser diode and/or a reflected portion of an energy beam, and to determine one or more parameters associated with irradiating the sequential layers of the powder bed **136** based at least in part on the detected monitoring beam. The one or more parameters determined by the monitoring system **162** may be utilized, for example, by the control system **104**, to control one or more operations of the additive manufacturing machine **102** and/or of the additive manufacturing system **100**. The monitoring system **162** may be configured to project a monitoring beam (not shown) and to detect a portion of the monitoring beam reflected from the build plane **130**. Additionally, and/or in the alternative, the monitoring system **162** may be configured to detect a monitoring beam that includes radiation emitted from the build plane, such as radiation from an energy beam reflected from the powder bed **136** and/or radiation emitted from a consolidation domain **137**, such as a melt pool domain, in the powder bed **136** generated by an energy beam and/or radiation emitted from a portion of the powder bed **136** adjacent to the consolidation domain **137**.

[0058] The monitoring system **162** may include componentry integrated as part of the additive manufacturing machine **102** and/or componentry that is provided separately from the additive manufacturing machine **102**. For example, the monitoring system **162** may include componentry integrated as part of the energy beam system **134**. Additionally, or in the alternative, the monitoring system **162** may include separate componentry, such as in the form of an assembly, that can be installed as part of the energy beam system **134** and/or as part of the additive manufacturing machine **102**.

[0059] Now turning to FIG. **2**, a transverse cross-sectional view of an exemplary additively manufactured three-dimensional object **114** is shown. The cross-sectional view shown in FIG. **2** may depict a digital representation **200** of a three-dimensional object **114**. The digital representation **200** of the three-dimensional object **114** may include image data and/or a rendered image from the image data. In some embodiments, the digital representation **200** may include or correspond to a micrographic image **201** of a three-dimensional object **114**. The digital representation **200** of the three-dimensional object **114** may be obtained from a test specimen taken from a three-dimensional object **114**, such as in the case of preparing a test specimen for micrographic image analysis. A digital representation **200**, such as a micrographic image **201** may be obtained through any suitable imaging technology, including optical metallography technology, and/or electron micrograph technology. For example, a digital representation **200** such as a micrographic image **201**, as depicted in FIG. **2**, may be obtained using an imaging system **203**, such as an imaging system **203** that includes scanning electron microscope technology, field emission scanning electron microscope technology, or the like. Test specimen prepared for optical metallography and/or electron micrography may be subjected to etching, anodizing, or other preparatory processes. The specific preparatory processes may be selected to provide a suitable specimen for the technology utilized. As shown in FIG. **2**, a digital representation **200** of a cross-sectional view, such as a micrographic image **201**, of an additively manufactured three-dimensional object **114** may reveal consolidation tracks **202** representing cross-sections of consolidation domains **137** formed by the respective consolidation domains **137** moving across the powder bed **136** when additively manufacturing the object **114**. A respective consolidation track **202** may correspond to a boundary of the consolidation domain **137** at the location of the respective consolidation track **202**. As shown in FIG. **2**, the consolidation domains **137** corresponding to respective consolidation tracks **202** may overlap one another, as the one or more energy beams **142**, **148** may follow consolidation tracks **202** configured and arranged to cause the respective consolidation domains **137** of a consolidation track **202** to overlap adjacent consolidation tracks **202**. In some embodiments the one or more energy beams **142**, **148** may reconsolidate at least a portion of an adjacent consolidation track **202**. By way of example, in the case of a melt pool domain, the one or more energy beams **142**, **148** may remelt adjacent consolidation tracks **202**. Additionally, or in the alternative, the one or more energy beams **142**, **148** may remelt a portion of one or more previous layers of the object **114** and/or of the powder bed **136**, and/or one or more adjacent consolidation tracks **202** from such one or more previous layers.

[0060] In some embodiments, the consolidation tracks **202** and/or the consolidation domains **137** may be determined visually, for example, with a human eye, from a visual rendering of a digital representation **200**, such as a micrographic image **201**. Additionally, or in the alternative, the consolidation tracks **202** may be determined from a digital representation **200**, such as a micrographic image **201**, using a computer vision program that detects pixels based on one or more optically determinable properties such as brightness, color, consolidation track pattern, etc. Exemplary computer vision programs may utilize a contour tracing algorithm and/or a boundary tracing algorithm. The digital representation **200**, such as a micrographic image **201**, may be embodies as image data and/or in the form of a visually rendered image.

[0061] In some embodiments, a boundary of a plurality of consolidation tracks **202** may be determined. One or more dimensional properties of the plurality of consolidation tracks **202** may be determined, such as one or more geometric properties, one or more algebraic properties, and/or one or more statistical properties. For example, a height (h), a width (w), and/or an area (A) of respective consolidation tracks **202** may be determined. Additionally, or in the alternative, an equation representing one or more dimensional properties of the respective consolidation tracks **202** may be determined, such as a boundary equation representing a boundary of the respective consolidation tracks **202**. While the digital representation **200**, such as a micrographic image **201**, depicted in FIG. **2** shows a transverse cross-sectional view, it will be appreciated that a digital representation **200**, such a micrographic image **201**, of an additively manufactured three-dimensional object **114** may be obtained from any one or more orientations. For example, as shown in FIGS. **3**A-**3**C a digital representation **200**, such a micrographic image **201**, may be obtained for a top cross-sectional view (FIG. **3**A), a longitudinal cross-sectional view (FIG. **3**B), and/or a transverse cross-sectional view (FIG. **3**C). In some embodiments, one or more consolidation tracks **202** and/or consolidation domains **137** may be partially obscured by adjacent consolidation tracks **202** and/or consolidation domains **137**. Partially obscured consolidation tracks **202** and/or consolidation domains **137** may be determined by extrapolation from unobscured portions and/or from a statistical inference determined from other consolidation tracks **202** and/or consolidation domains **137**.

[0062] One or more properties of the plurality of consolidation tracks **202** may be determined from digital representations **200**, such micrographic images **201**, corresponding to respective orientations of the object **114**, including height (h), width (w), area (A), and/or equations representing one or more dimensional properties of the respective consolidation tracks **202**. A three-dimensional representation of a consolidation track **202** may be determined from a plurality of digital representations **200**, such as digital representations **200** (e.g., micrographic images **201**) representing top, longitudinal, and/or transverse cross-sectional views respectively shown in FIGS. **3**A-**3**C.

[0063] As shown in FIGS. **3**A-**3**C, in some embodiments, a computer vision program may be utilized to determine a consolidation boundary **300**, such as a melt pool boundary, from a digital representation **200**, such as a micrographic image **201**, of a three-dimensional object. Additionally, or in the alternative, a consolidation boundary **300**, such as a melt pool boundary, may be determined visually, for example, with a human eye, from a visual rendering of a digital representation **200**, such as a micrographic image **201**. As shown, a consolidation boundary **300** may have somewhat irregular boundaries, which may be attributable at least in part to variations in the additive manufacturing process, such as, in the case of a powder bed technology, variations in heat transfer from the consolidation domain **137** to the powder bed **136** and/or adjacent consolidation tracks **202**.

[0064] As shown in FIGS. **4**A-**4**C, an approximate consolidation domain **400** may be determined for one or more consolidation tracks **202**, such as for a consolidation boundary **300**. An approximate consolidation domain **400** may represent an approximation of a domain occupied by a consolidation track **202**. An approximate consolidation domain **400** may have an approximate consolidation boundary **402** that represents an approximation of a consolidation boundary **300**. An approximate consolidation domain **400** may be determined using an algorithm, such as a curve fitting algorithm. Additionally, or in the alternative, an approximate consolidation domain may be determined using a data library that includes geometric approximation candidates. A geometric approximation candidate may be selected using by comparing one or more geometric approximation candidates to one or more approximate consolidation domains **400** and/or consolidation boundaries **300**. In some embodiments, the one or more geometric approximation candidates may be selected by visual comparison, for example, with a human eye, to one or more approximate consolidation domains **400** and/or consolidation boundaries **300**. Additionally, or in the alternative, the one or more geometric approximation candidates may be selected using a computer algorithm, such as a computer vision program, configured to compare the one or more geometric approximation candidates to one or more approximate consolidation domains **400** and/or consolidation boundaries **300**.

[0065] In some embodiments, geometric approximation candidates may be generated using graphic design software, drafting software, computer-aided design software, drawing software, or the like. Additionally, or in the alternative, geometric approximation candidates may be generated using a curve fitting algorithm. A data library may include a plurality of geometric approximation candidates generated using a curve fitting algorithm. An approximate consolidation domain **400** and/or an approximate consolidation boundary **402** may be determined with a statistical confidence level. For example, an approximate consolidation domain **400** and/or an approximate consolidation boundary **402** may be determined within a range that represents a statistical confidence level.

[0066] Exemplary curve fitting algorithms may include algebraic fitting algorithms, geometric fitting algorithm, and the like. In some embodiments, such as in the case of an algebraic fitting algorithm, an approximate consolidation domain **400** may be determined at least in part using a least squares regression, including a polynomial regression. At least a portion of an approximate consolidation domain **400** may be determined using a conic section function, a parametric function, and/or a trigonometric function. An exemplary function may correspond, for example, to at least a portion of a circle, an ellipses, parabolic arc, and/or a hyperbolic arc. In some embodiments, such as in the case of a geometric fitting algorithm, a consolidation domain **400** may be determined at least in part using an algorithm that minimizes the square sum of the shortest distances between the approximate consolidation domain and the consolidation boundary **300**, for example, using nonlinear minimization. The square sum of the shortest distances may be determined using costs functions. The cost functions may be minimized using a coordinate based algorithm and/or a distance-based algorithm. Additionally, or in the alternative, the cost functions may be minimized using a total method and/or a variable-separation method. For example, an exemplary geometric fitting algorithm may utilize a combination of a variable-separation method and a coordinate-based algorithm.

[0067] Exemplary geometric approximation candidates in a data library may be derived from any number of geometric domains having any number of configurations, arrangements, and/or dimensions. Exemplary geometric domains may include at least a segment of any one or more polygonal domains, and/or at least a segment of any one or more circular, elliptical, parabolic, and/or hyperbolic domains, and/or a combination thereof. In some embodiments, geometric approximation candidates may be determined and/or generated using a curve fitting algorithm and stored in a data library for use in determining an approximate consolidation domain **400**. Additionally, or in the alternative, exemplary geometric approximation candidates may be determined and/or generated based at least in part on one or more geometric shapes, and/or based at least in part on one or more dimensional properties of a geometric shape, such as a width and/or a height, and so forth. For example, a user and/or a computer program may select a geometric shape and/or one or more dimensional properties of the geometric shape. The user and/or the computer may determine the geometric approximation candidate based at least in part on the selected geometric domain and/or the one or more dimensional properties thereof.

[0068] An approximate consolidation domain **400** may be determined at least in part form a geometric approximation candidate using visual comparison, for example, with a human eye. Additionally, or in the alternative, an approximate consolidation domain **400** may be determined at least in part form a geometric approximation candidate using a comparison algorithm, such as a boundary matching algorithm, a shape matching algorithm, a boundary based shape similarity algorithm, or the like. An exemplary comparison algorithm may be based at least in part on a Hamming distance algorithm and/or a Hausdorff distance algorithm. A Hamming distance algorithm may be configured to measure the area of symmetric difference between a geometric approximation candidate and a consolidation track **202**, such as a consolidation boundary **300**. When a geometric approximation candidate and a consolidation track **202**, such as a consolidation boundary **300**, are identical, and properly aligned, the Hamming distance will be zero. The Hamming distance increases as a geometric approximation candidate and a consolidation track **202** increasingly differ, up to a maximum Hamming distance equal to the sum of the area of the geometric approximation candidate and the consolidation track **202** in the case when they are completely disjoint. A Hausdorff distance algorithm may be configured to identify a maximum of a distance form a point on a geometric approximation candidate to a nearest point on a consolidation track **202**, such as a consolidation boundary **300**.

[0069] In some embodiments, an exemplary comparison algorithm may utilize a skeleton-based shape matching, for example, using skeletal voxels connected in a stick-figure representation of the respective geometric approximation candidates and consolidation tracks **202**. The skeletal voxels may be determined using volumetric thinning. The skeletal voxels resulting from volumetric thinning may be clustered and connected to provide a skeletal graph suitable for shape graph matching.

[0070] Additionally, or in the alternative, an exemplary comparison algorithm may utilize a neural network. An exemplary neural network may categorize a plurality of geometric approximation candidates based on one or more classification features, such as type of shape (e.g., polygonal, elliptical, etc.), area, number of sides, and number of curves, and so forth. A neural network training algorithm may be utilized to determine a classification algorithm that determines a classification for a consolidation track **202**, such as a consolidation boundary **300**. The consolidation track **202** may be compared to one or more geometric approximation candidates that match the one or more classification features of the consolidation track **202**. A shape matching algorithm may be utilized to determine a geometric approximation candidate from among a plurality that match the one or more classification features.

[0071] A plurality of geometric approximation candidates, such as from a data library, may be compared to a consolidation track **202**, such as a consolidation boundary **300**. An approximate consolidation domain **400** may be determined from a geometric approximation candidate selected, for example, based at least in part on a comparison a consolidation track **202**. In some embodiments, a geometric approximation candidate may be selected as an approximate consolidation domain **400** for a consolidation track **202** when the geometric approximation candidate satisfies one or more selection criteria. For example, a geometric approximation candidate may be selected as an approximate consolidation domain **400** for a consolidation track **202** when the geometric approximation candidate satisfies a shape similarity threshold with respect to the consolidation track **202**. Additionally, or in the alternative, a geometric approximation candidate may be selected from among a plurality based at least in part on a closest degree of similarity to the consolidation track **202** relative to the other geometric approximation candidates among the plurality.

[0072] In some embodiments, a selected geometric approximation candidate may be augmented to increase a degree of similarity to the consolidation track **202**. For example, a shape augmentation algorithm may be utilized to conform the selected geometric approximation candidate to the consolidation track **202**. The shape augmentation algorithm may be configured to apply one or more augmentation operations configured, for example, to resize, stretch, shrink, skew, and/or twist, at least a portion of the selected geometric approximation candidate.

[0073] Turning now to FIG. **5**, an approximate consolidation domain **400** may be determined from a plurality of consolidation tracks **202**, such as a multitude of consolidation tracks **202**. A plurality of consolidation tracks **202** may be analyzed to determine statistical relationship between one or more irradiation parameters and one or more dimensional properties of the consolidation tracks **202** formed when irradiating a powder material **120** with respective irradiation parameter values. Additionally, or in the alternative, a plurality of consolidation domains **400** may be analyzed to determine statistical relationship between one or more irradiation parameters and one or more dimensional properties of the consolidation domains **400** determined from the consolidation tracks **202**, and/or between the one or more dimensional properties of the consolidation domains **400** and one or more dimensional properties of the consolidation tracks **202** formed when irradiating with respective irradiation parameter values. The quantity of consolidation tracks **202** may be selected to satisfy a statistical confidence level for respective relationships being analyzed. Exemplary irradiation parameters that may be considered include, by way of example, power, intensity, intensity profile, power density, spot size, spot shape, scanning pattern, scanning speed, and so forth. An analysis may be performed and/or repeated for a number of different powder materials, such as powder materials having different elemental compositions and/or powder materials having different particle sizes and/or size distributions. In some embodiments, one or more irradiation parameters may be varied. Additionally, or in the alternative, a plurality of irradiation parameters may remain constant.

[0074] The consolidation tracks **202** may be generated by irradiation performed with a plurality of different irradiation parameter values. One or more dimensional properties of a consolidation track **202** and/or an approximate consolidation domain **400** may vary depending on a value for one or more irradiation parameter when irradiating the build plane **130** to form the consolidation tracks **202**. As shown in FIG. **5**, in some embodiments, an irradiation parameter matrix **500** may be provided. The irradiation parameter matrix **500** may include a plurality of nodes **502** that define respective irradiation parameter values utilized when forming the consolidation track **202** corresponding to the respective node **502**. The consolidation tracks **202** shown in the irradiation parameter matrix **500** may be formed by irradiating a build plane **130** with the respective irradiation parameters having values as specified in the irradiation parameter matrix **500**. The approximate consolidation domains **400** shown in the irradiation parameter matrix **500** may be determined from the consolidation tracks **202** formed by irradiating the build plane **130** with the respective irradiation parameters having values as specified in the irradiation parameter matrix **500**.

[0075] By way of example, a first node **504** may define a plurality of irradiation parameter values for forming a first consolidation track **506**, and a second node **508** may define a plurality of irradiation parameter values for forming a second consolidation track **510**. In some embodiments, at least one irradiation parameter value may differ as between the first node **504** and the second node **508**. Additionally, or in the alternative, the first node **504** and the second node **508** may have at least one common irradiation parameter value. For example, the first node **504** may include a first irradiation parameter **512** that has a first value **514**, and a second irradiation parameter **516** that has a first value **518**. The second node **508** may include the first irradiation parameter **512** and the second irradiation parameter **516**, with the second irradiation parameter **516** having a second value **520** and the first irradiation parameter **512** maintaining the first value **514**. A third node **522** may include the first irradiation parameter **512** having a third value **524** and the second irradiation parameter **516** having a third value **526**.

[0076] An irradiation parameter matrix **500** may include any number of nodes **502** relating any number of irradiation parameters at any number of values. The specific number of nodes **502** in an irradiation parameter matrix **500** may be selected based at least in part on the range of values for variable irradiation parameters with respect to which irradiation may be performed. Additionally, or in the alternative, the specific number of nodes **502** in an irradiation parameter matrix **500** may be selected based at least in part to determine a statistically significant correlation between respective irradiation parameters and one or more dimensional properties of resulting consolidation tracks **202** and/or the approximate consolidation domains **400** determined for the resulting consolidation tracks **202**. In some embodiments, one or more irradiation parameters may be varied. Additionally, or in the alternative, a plurality of irradiation parameters may remain constant.

[0077] A given node **502** in an irradiation parameter matrix **500** may include any number of samples. The quantity of samples for respective nodes **502** may be determined at least in part to provide a statistical confidence level for one or more dimensional properties of the respective consolidation tracks **202** and/or approximate consolidation domains **400**, such as a statistical confidence level for one or more geometric properties, algebraic properties, and/or statistical properties.

[0078] An irradiation parameter matrix **500** may be developed for a plurality of irradiation devices **138**, **140** and/or for a plurality of regions of a build plane **130**. Additionally, or in the alternative, an irradiation parameter matrix **500** may include nodes **502** corresponding to respective ones of a plurality of irradiation devices **138**, **140** and/or corresponding to respective ones of a plurality of regions of a build plane **130**. For example, a first irradiation parameter matrix **500** may be developed for a first irradiation device **138** and a second irradiation parameter matrix **500** may be developed for a second irradiation device **140**. The first and/or second irradiation parameter matrix **500** may include nodes corresponding to a first build plane region **146**, a second build plane region **152**, and/or an interlace region **154**. Additionally, or in the alternative, a third, fourth, and/or fifth irradiation parameter matrix **500** may be developed for a first build plane region **146**, a second build plane region **152**, and/or an interlace region **154**. The third, fourth, and/or fifth irradiation parameter matrix **500** may include nodes corresponding to the first irradiation device **138** and/or the second irradiation device **140**.

[0079] While the irradiation parameter matrix **500** shown in FIG. **5** depicts top cross-sectional views of consolidation tracks **202** and corresponding approximate consolidation domains **400**, it will be appreciated that an irradiation parameter matrix may include consolidation tracks **202** and corresponding approximate consolidation domains **400** for any one or more spatial domains, including two dimensional and/or three-dimensional domains. For example, an irradiation parameter matrix **500** may include top cross-sectional domains, longitudinal cross-sectional domains, and/or transverse cross-sectional domains. Additionally, or in the alternative, one or more two-dimensional domains may be combined for provide a three-dimensional domain.

[0080] Now turning to FIGS. **6**A-**6**C, in some embodiments, an approximate consolidation domain **400** and/or an approximate consolidation boundary **402** may be determined based at least in part on one or more statistical parameters, for example, based at least in part on data from an irradiation parameter matrix **500**. Additionally, or in the alternative, an approximate consolidation domain **400** and/or an approximate consolidation boundary **402** may be determined from one or more discrete measurements without requiring use of an irradiation parameter matrix **500**. In some embodiments, an approximate consolidation domain **400** may include an approximate consolidation boundary **402** that represents a mean, a median, or a mode. The approximate consolidation domain **400** and/or the approximate consolidation boundary **402** may be determined with a statistical confidence level. Additionally, or in the alternative, an approximate consolidation domain **400** may include an inward approximate consolidation boundary **402** and/or an outward approximate consolidation boundary **402** that represents a statistical confidence interval or range. The statistical confidence interval or range may be based at least in part on a statistical variance and/or a standard deviation.

[0081] FIGS. **6**A-**6**C show probability maps of approximate consolidation domains **400**. As shown in FIGS. **6**A-**6**C, an approximate consolidation domain **400** may include a 1-sigma outward approximate consolidation boundary **600** and a 1-sigma inward approximate consolidation boundary **602**. A range between the 1-sigma outward approximate consolidation boundary **600** and the 1-sigma inward approximate consolidation boundary **602** may represent one standard deviation for the approximate consolidation domain **400** and/or the approximate consolidation boundary **402**. Additionally, or in the alternative, an approximate consolidation domain **400** may include a 2-sigma outward approximate consolidation boundary **604** and a 2-sigma inward approximate consolidation boundary **606**. A range between the 2-sigma outward approximate consolidation boundary **604** and the 2-sigma inward approximate consolidation boundary **606** may represent two standard deviations for the approximate consolidation domain **400** and/or the approximate consolidation boundary **402**. Additionally, or in the alternative, an approximate consolidation domain **400** may include a 3-sigma outward approximate consolidation boundary **608** and a 3-sigma inward approximate consolidation boundary **610**. A range between the 3-sigma outward approximate consolidation boundary **608** and the 3-sigma inward approximate consolidation boundary **610** may represent three standard deviations for the approximate consolidation domain **400** and/or the approximate consolidation boundary **402**. It will be appreciated that the outward and inward approximate consolidation boundaries are provided by way of example and are not intended to be limiting. In fact, an approximate consolidation domain **400** may include an outward approximate consolidation boundary and/or an inward approximate consolidation boundary corresponding to any sigma level, including 4-sigma, 5-sigma, 6-sigma, and so forth.

[0082] As shown in FIGS. **7**A-**7**C, one or more dimensional properties of a consolidation track **202** formed by irradiating a build plane **130** with given irradiation parameter values may have a distribution of probable values. The distribution of probable values for a given dimensional property may be represented by a probability curve **700**, such as a normal distribution curve, a Gaussian distribution curve, a Poisson distribution curve, a Chi-square distribution curve, or the like. The distribution of probable values represented by the probability curves **700** shown in FIGS. **7**A-**7**C may correspond to data from an irradiation parameter matrix **500** and/or to the one or more statistical parameters determined therefrom. Additionally, or in the alternative, the distribution of probable values represented by the probability curves **700** shown in FIGS. **7**A-**7**C may correspond to the approximate consolidation domain **400** and/or the approximate consolidation boundary **402** determined from the irradiation parameter matrix **500** and/or to the one or more statistical parameters determined thereof.

[0083] By way of example, in some embodiments, the probability curves **700** shown in FIGS. **7**A-**7**C may represent a distribution for a dimensional property of a consolidation track **202** and/or a consolidation boundary **300**, and/or a dimensional property of an approximate consolidation domain **400** and/or an approximate consolidation boundary **402**. For example, the probability curve **700** shown in FIG. **7**A may represent a distribution for a width, length, or area of a top cross-sectional domain. The probability curve **700** shown in FIG. **7**B may represent a distribution for a width, length, or area of a longitudinal cross-sectional domain. The probability curve **700** shown in FIG. **7**C may represent a distribution for a width, length, or area of a transverse cross-sectional domain. Additionally, or in the alternative, the probability curves **700** shown in FIGS. **7**A-**7**C may represent a parameter, such as a variable parameter or a constant parameter, of an equation representing one or more dimensional properties of the respective consolidation tracks **202** may be determined, such as a boundary equation representing a boundary of the respective consolidation tracks.

[0084] Now referring to FIGS. **8**A-**8**E, FIGS. **9**A-**9**D, and **10**A-**10**E, exemplary simulated additively manufactured three-dimensional and exemplary additive manufacturing simulations will be further described. FIGS. **8**A-**8**E schematically depict exemplary simulated additively manufactured three-dimensional objects **800**. The simulated additively manufactured three-dimensional objects **800** include a plurality of simulated consolidation layers **802** respectively including a plurality of approximate consolidation domains **400**. The geometric dimensions, and/or the configuration and arrangement, of the simulated consolidation layers **802** and the respective approximate consolidation domains **400** may be determined as described herein. In some embodiments, one or more simulated consolidation artifacts **804** may be determined in the simulated additively manufactured three-dimensional objects **800**. One or more material properties of an actually additively manufactured object **114** may be determined based at least in part on the presence of one or more simulated consolidation artifacts **804**. Such one or more material properties of an additively manufactured object **114** may be determined based at least in part on the presence of simulated consolidation artifacts **804** in a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800**. Exemplary material properties that may be determined include: porosity, void sizes, void area, void aspect ratio, void maximum size, density, elastic modulus, yield strength, ductility, hardness, surface finish, mass, fatigue limit, creep, and so forth. Further exemplary material properties that may be determined include grain structures and/or crystalline structures, such as coarse grain regions, microcrystalline grain regions, nanocrystalline grain regions, amorphous regions, precipitates, crystalline dislocations, twinning dislocations, and the like. Further exemplary material properties that may be determined include unmelted powder particles, unsintered powder particles, unbound binder particles, and the like.

[0085] Exemplary simulated consolidation artifacts **804** may include void elements **806** and/or overlap elements **808**. Void elements **806** represent portions of the simulated additively manufactured three-dimensional object **800** that are not occupied by at least one approximate consolidation domains **400**. Overlap elements **808** represent portions of the simulated additively manufactured three-dimensional object **800** that are overlapped by a plurality of approximate consolidation domains **400**. Overlap elements may include portions of the simulated additively manufactured three-dimensional object **800** that include an overlap of two, three, four, or more approximate consolidation domains **400**. Void elements **806** may correspond to voids, pores, incomplete melting or sintering or non-sintered or non-melted powder material **120**, or regions without binder material, or the like, in an actual three-dimensional object **114** manufactured based on the simulated additively manufactured three-dimensional object **800**. Overlap elements **808** may correspond to solid portions of an actual three-dimensional object **114** manufactured based on the simulated additively manufactured three-dimensional object **800**. In some embodiments, too little overlap between approximate consolidation domains **400** may correspond to voids, pores, incomplete melting or sintering or non-sintered or non-melted powder material **120**, or the like in a three-dimensional object **114** manufactured based on the simulated additively manufactured three-dimensional object **800**. However, in some embodiments, too much overlap between approximate consolidation domains **400** and/or too many overlap elements **808** may also introduce voids, pores, incomplete melting or sintering or non-sintered or non-melted powder material **120**, or the like in a three-dimensional object **114** manufactured based on the simulated additively manufactured three-dimensional object **800**. For example, too much overlap between approximate consolidation domains **400** and/or too many overlap elements **808** may correspond to excessively high localized temperatures that may lead to vaporization, sputtering, or the like in the three-dimensional object **114**. By way of example, the presence and/or quantity of overlap elements **808** that include more than two overlapping approximate consolidation domains **400**, such as three, four, or more approximate consolidation domains **400**, may correspond to excessively high localized temperatures that may lead to vaporization, sputtering, or the like in the three-dimensional object **114**. Such vaporization, sputtering, or the like may introduce voids, pores, incomplete melting or sintering or non-sintered or non-melted powder material **120**, or the like in the three-dimensional object **114**.

[0086] The presence of void elements **806** may depend at least in part on the configuration and arrangement of the respective approximate consolidation domains **400** in the respective simulated consolidation layers **802** relative to one another and/or on the configuration and arrangement of the respective simulated consolidation layers **802** relative to one another. Additionally, or in the alternative, the quantity and/or size of void elements **806** may depend at least in part on the configuration and arrangement of the respective approximate consolidation domains **400** in the respective simulated consolidation layers **802** relative to one another and/or on the configuration and arrangement of the respective simulated consolidation layers **802** relative to one another. The presence of overlap elements **808** may depend at least in part on the configuration and arrangement of the respective approximate consolidation domains **400** in the respective simulated consolidation layers **802** relative to one another and/or on the configuration and arrangement of the respective simulated consolidation layers **802** relative to one another. Additionally, or in the alternative, the quantity and/or size of overlap elements **808** may depend at least in part on the configuration and arrangement of the respective approximate consolidation domains **400** in the respective simulated consolidation layers **802** relative to one another and/or on the configuration and arrangement of the respective simulated consolidation layers **802** relative to one another.

[0087] It will be appreciated that the simulated consolidation artifacts **804** described herein, such as the void elements **806** and the overlap elements **808**, are provided by way of example and not to be limiting. In fact, the simulated consolidation artifacts **804** may include any one or more types of artifacts that may be determined in an additively manufactured three-dimensional object **114**, such as by way of a digital representation **200**, such as a micrographic image **201**, or the like. Further exemplary simulated consolidation artifacts **804** may include unmelted powder particles, unsintered powder particles, unbound binder particles, and the like. Additionally, or in the alternative, exemplary simulated consolidation artifacts **804** may include grain structures and/or crystalline structures, such as coarse grain structures, microcrystalline grain structures, nanocrystalline grain structures, amorphous regions, precipitates, crystalline dislocations, twinning dislocations, and the like.

[0088] In some embodiments, the simulated consolidation artifacts **804** may be determined by way of a geometric analysis of the simulated additively manufactured three-dimensional object **800**. Additionally, or in the alternative, the simulated consolidation artifacts **804** may be determined using a computer vision program such as a contour tracing algorithm and/or a boundary tracing algorithm. In some embodiments, respective approximate consolidation domains **400** and/or one or more regions thereof may be assigned one or more computer generated colorimetry parameter, such as a grayscale parameter, an RGB color parameter, and/or a transparency parameter. The computer vision program may be configured to determine the one or more simulated consolidation artifacts **804** based at least in part on the computer generated colorimetry parameter assigned to the respective approximate consolidation domains **400** and/or to the one or more regions thereof.

[0089] By way of example, as shown in FIGS. **8**A-**8**E, respective approximate consolidation domains **400** have been assigned a grayscale parameter and a transparency parameter, such that overlap elements **808** may appear relatively darker, and void elements **806** may appear white. Overlap elements **808** may appear increasingly darker with increasing number of approximate consolidation domains **400** overlapping one another. For example, as shown in FIG. **8**A, a relatively wide hatch width **810** and/or a relatively tall layer height **816** may yield a simulated additively manufactured three-dimensional object **800** with a relatively high prevalence of void elements **806** as indicated, for example, by whitespace in the simulated additively manufactured three-dimensional object **800**. Additionally, or in the alternative, a relatively higher degree of overlapping approximate consolidation domains **400** as shown in FIGS. **8**B and **8**C may yield fewer void elements **806** and/or a relatively higher prevalence of overlap elements **808**, as indicated, for example, by darker grayscale values.

[0090] It will be appreciated that the embodiments described herein, such as with reference to FIGS. **8**A-**8**E, are given by way of example only and not to be limiting. In fact, other computer generated colorimetry parameters may be utilized without departing from the scope of the present disclosure. Additionally, or in the alternative, other computer vision programs may be utilized in addition or in the alternative those described herein without departing from the scope of the present disclosure.

[0091] In some embodiments, the respective scaling of one or more computer generated colorimetry parameters may be determined based at least in part on a probability distribution, a statistical variance, and/or a standard deviation, as described herein. Respective ones of one or more computer generated colorimetry parameters may correspond to respective material properties depicted in the simulated additively manufactured three-dimensional object **800**.

[0092] By way of example, FIG. **8**D shows an exemplary simulated additively manufactured three-dimensional object **800**. The simulated additively manufactured three-dimensional object **800** may include a plurality of void elements **806** determined in accordance with the present disclosure. In some embodiments, as shown, for example, in FIG. **8**D, a simulated additively manufactured three-dimensional object **800** may include one or more simulated consolidation artifacts **804**, such as void elements **806**, may be depicted by a computer generated colorimetry parameter. Other portions of the simulated additively manufactured three-dimensional object **800** may be removed or omitted from the simulated additively manufactured three-dimensional object **800** to more readily reveal the one or more simulated consolidation artifacts **804**, such as void elements **806**. Additionally, or in the alternative, the one or more simulated consolidation artifacts **804**, such as void elements **806**, may be depicted with a high-contrast computer generated colorimetry parameter. For example, as shown in FIG. **8**D, the void elements **806** may be depicted in black and the remainder of the simulated additively manufactured three-dimensional object **800** may be depicted in white.

[0093] In some embodiments, a probability distribution of one or more simulated consolidation artifacts **804**, such as void elements **806**, may be determined. For example, FIG. **8**E shows an exemplary probability distribution of void elements **806** corresponding to the simulated additively manufactured three-dimensional object **800** shown in FIG. **8**D. A probability distribution for one or more other simulated consolidation artifacts **804** may be determined similarly, such as for overlap elements **808**. The probability distribution may include a distribution of the quantity of simulated consolidation artifacts **804**, such as a distribution of the quantity of void elements **806** as a function of a dimensional property of the void elements, such as cross-sectional width and/or area, or the like. One or more material properties, such as porosity, void sizes, void area, void aspect ratio, void maximum size, density, elastic modulus, yield strength, ductility, hardness, surface finish, mass, fatigue limit, creep, and the like, may be determined for an additively manufactured three-dimensional object **114** to be manufactured based at least in part on a simulated additively manufactured three dimensional object **800** determined from an additive manufacturing simulation. In some embodiments, the one or more material properties may be determined based at least in part on the probability distribution of the one or more simulated consolidation artifacts **804**. Additionally, or in the alternative, one or more material properties may be determined based at least in part on one or more deterministic properties of the one or more simulated consolidation artifacts **804**, such as numerical thresholds, maximums, minimums, or the like for one or more simulated consolidation artifacts **804**.

[0094] As shown in FIGS. **8**A-**8**C, **9**A-**9**D, and **10**A-**10**E, a plurality of approximate consolidation domains **400** may be configured and arranged relative to one another to simulate respective layers of consolidation tracks **202** in a build plane **130**. The simulated layers of consolidation tracks **202** may be utilized in an additive manufacturing simulation, such as to provide a simulated additively manufactured three-dimensional object **800**. A plurality of approximate consolidation domains **400** may be configured and arranged to define a simulated consolidation layer **802**. In some embodiments, one or more material properties of an actually additively manufactured object **114** may be determined based at least in part on one or more dimensional properties of the plurality of approximate consolidation domains **400**. For example, the one or more material properties may be determined based at least in part on the geometric shape of the plurality of approximate consolidation domains **400** and/or the configuration and arrangement of the plurality of approximate consolidation domains **400** in a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800**. Additionally, or in the alternative, the one or more material properties may be determined based at least in part on one or more geometric properties, one or more algebraic properties, and/or one or more statistical properties.

[0095] As shown, for example, in FIGS. **9**A-**9**D, the respective approximate consolidation domains **400** in a simulated consolidation layer **802** may be situated horizontally relative to one another according to a hatch width (H.sub.w) **810**. The hatch width **810** may be determined relative to a longitudinal axis (A.sub.L) **812** of an approximated consolidation domain **400** and/or a vertical axis (A.sub.V) **814** of an approximated consolidation domain **400**. The hatch width **810** may be selected to provide a suitable overlap between adjacent approximate consolidation domains **400**. The respective simulated consolidation layers **802** may be situated vertically relative to one another according to a layer height (L.sub.h) **816**. The layer height **816** may be determined relative to a virtual build plane **818** corresponding to a respective simulated consolidation layer **802**. The virtual build plane **818** may be determined based at least in part on a top surface of the respective approximate consolidation domains **400** in the respective simulated consolidation layer **802**. The layer height **816** may be selected to provide a suitable overlap between sequential simulated consolidation layers **802**.

[0096] The hatch width **810** and/or the layer height **816** may be selected based on the applicable additive manufacturing technology. By way of example, for an additive manufacturing technology that utilizes a powder bed technology, the hatch width **810** may be from about 10 micrometers (μm) to about 1000 μm, or such as from about 10 μm to about 200 μm. Additionally, or in the alternative, the layer height **816** may be from about 10 μm to about 1000 μm, such as from about 10 μm to about 200 μm. In other embodiments, the hatch width **810** and/or the layer height **816** may be from about 10 μm to about 2 millimeters (mm), such as from about 10 μm to about 200 μm, such as from about 200 μm to about 2 mm, or such as from about 2 mm to about 50 mm.

[0097] As shown, for example, in FIG. **9**A, a simulated additively manufactured three-dimensional object **800** may include one or more simulated consolidation artifacts **804**, such as void elements **806** and/or overlap elements **808**. As shown, a relatively large hatch width **810** and/or a relatively large layer height **816** may introduce void elements **806** in the simulated additively manufactured three-dimensional object **800**. For example, FIG. **9**A shows a void element **806** defined by adjacent approximate consolidation boundaries **402** of a plurality of approximate consolidation domains **400**. Additionally, or in the alternative, a relatively small layer height **816** and/or a relatively small hatch width may increase the presence of overlap elements **808** in the simulated additively manufactured three-dimensional object **800**. For example, FIG. **9**A shows an overlap element **808** that includes two overlapping approximate consolidation domains **400**.

[0098] As shown in FIG. **9**B, the presence of void elements **806**, and/or the quantity and/or size of void elements **806**, in the simulated additively manufactured object **800** may be eliminated or reduced, for example, by utilizing a relatively small layer height **816**. For example, FIG. **9**B shows a void element **806** that is relatively smaller than the corresponding void element **806** in FIG. **9**A. Additionally, or in the alternative, the presence of overlap elements **808**, and/or the quantity and/or size of overlap elements **808**, may be increased in the simulated additively manufactured object **800**, for example, by utilizing a relatively small layer height **816**. For example, FIG. **9**B shows an overlap element **808** at a location where in FIG. **9**A there exists a void element **806**.

[0099] As shown in FIG. **9**C, the presence of void elements **806**, and/or the quantity and/or size of void elements **806**, in the simulated additively manufactured object **800** may be eliminated or reduced, for example, by utilizing a relatively small hatch width **810**. Additionally, or in the alternative, the presence of overlap elements **808**, and/or the quantity and/or size of overlap elements **808**, may be increased in the simulated additively manufactured object **800**, for example, by utilizing a relatively small hatch width **810**. For example, FIG. **9**C shows an overlap element **808** at a location where in FIG. **9**A there exists a void element **806**. By way of example, the overlap element in FIG. **9**B includes four overlapping approximate consolidation domains.

[0100] In some embodiments, the presence of void elements **806** may depend at least in part on one or more irradiation parameters. The configuration and arrangement of the respective approximate consolidation domains **400** may depend at least in part on one or more irradiation parameters. For example, increasing beam power and/or decreasing scanning speed may increase one or more dimensions of an approximate consolidation domains **400**, while decreasing beam power and/or increasing scanning speed may decrease one or more dimensions of an approximate consolidation domains **400**. In various embodiments, any one or more irradiation parameters may influence one or more dimensional parameters of an approximate consolidation domains **400**, including power, intensity, intensity profile, power density, spot size, spot shape, scanning pattern, scanning speed, and so forth. The particular influence may be determined using an irradiation parameter matrix **500**.

[0101] As shown in FIG. **9**D, by comparison to FIG. **9**C, one or more irradiation parameters with irradiation parameter values that have the effect of decreasing one or more dimensions of an approximate consolidation domains **400** may increase the presence of void elements **806** and/or may decrease the presence of overlap elements **808**. Additionally, or in the alternative, one or more irradiation parameters with irradiation parameter values that have the effect of decreasing one or more dimensions of an approximate consolidation domains **400** may increase the quantity and/or size of void elements **806**, and/or may decrease the quantity and/or size of overlap elements **808**. As shown in FIG. **9**C, the presence of void elements **806**, and/or the quantity and/or size of void elements **806**, in the simulated additively manufactured object **800** may be eliminated or reduced relative to FIG. **9**D, for example, by selecting irradiation parameter values so as to increase one or more dimensions of an approximate consolidation domains **400**. Additionally, or in the alternative, the quantity and/or size of overlap elements may be increased relative to FIG. **9**D, for example, by selecting irradiation parameter values so as to increase one or more dimensions of an approximate consolidation domains **400**.

[0102] Referring now to FIGS. **10**A-**10**E, further exemplary configurations and arrangements of approximate consolidation domains **400** that may be included in a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800** will be described. As shown in FIGS. **10**A and **10**B, in some embodiments, a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800** may include approximate consolidation domains **400** that share one or more common dimensional properties, such as one or more common geometric properties, one or more common algebraic properties, and/or one or more common statistical properties. For example, the approximate consolidation domains **400** may be defined at least in part by the same geometric shape. Additionally, or in the alternative, the approximate consolidation domains **400** may be defined at least in part by the same algorithm, such as the same curve fitting algorithm, the same algebraic fitting algorithm, and/or the same geometric fitting algorithm, or the like. The one or more dimensional properties of the approximate consolidation domains **400** in a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800** may be determined at least in part from data determined from an irradiation parameter matrix **500**. For example, the approximate consolidation domain **400** may include an approximate consolidation boundary **402** that represents a mean, a median, or a mode determined at least in part from the irradiation parameter matrix **500**.

[0103] In some embodiments, as shown in FIG. **10**C, a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800** may include at least some approximate consolidation domains **400** that differ from one another in respect of one or more dimensional properties, such as one or more geometric properties, one or more algebraic properties, and/or one or more statistical properties. For example, at least some of the approximate consolidation domains **400** may be defined at least in part by a different geometric shape relative to one another. Additionally, or in the alternative, at least some of the approximate consolidation domains **400** may be defined at least in part by a different algorithm, such as a different curve fitting algorithm, a different algebraic fitting algorithm, and/or a different geometric fitting algorithm, or the like. The one or more dimensional properties of the approximate consolidation domains **400** in a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800** may be determined at least in part from data determined from an irradiation parameter matrix **500**. For example, the approximate consolidation domains **400** may include an approximate consolidation boundary **402** that falls within a statistical confidence interval or range, such as a statistical variance and/or a standard deviation.

[0104] A plurality of approximate consolidation domains **400** may be determined for a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800** based at least in part on a statistical confidence interval or range, such as a statistical variance and/or a standard deviation. The plurality of approximate consolidation domains **400** may have one or more dimensional properties representative of a statistical confidence interval or range, such as a statistical variance and/or a standard deviation. For example, the plurality of approximate consolidation domains **400** may include one or more dimensional properties, such as one or more geometric properties, one or more algebraic properties, and/or one or more statistical properties, that are representative of a statistical confidence interval or range, such as a statistical variance and/or a standard deviation. The statistical confidence interval or range, such as a statistical variance and/or a standard deviation may be determined at least in part from data determined from an irradiation parameter matrix **500**. The statistical confidence interval or range, such as a statistical variance and/or a standard deviation, may be utilized to determine one or more dimensional properties, such as a geometric shape, for a plurality of approximate consolidation domains **400**. Additionally, or in the statistical confidence interval or range, such as a statistical variance and/or a standard deviation, may be utilized to determine a curve fitting algorithm, an algebraic fitting algorithm, and/or a geometric fitting algorithm, for a plurality of approximate consolidation domains **400**.

[0105] In some embodiments, the presence of one or more simulated consolidation artifacts **804**, such as void elements **806** and/or overlap elements **808**, may be determined based at least in part on one or more dimensional properties, such as the geometric shape and/or a corresponding algorithm, of the plurality of approximate consolidation domains **400**. Additionally, or in the alternative, the presence of one or more simulated consolidation artifacts **804** may be determined based at least in part on the configuration and arrangement of the plurality of approximate consolidation domains **400** in a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800**. For example, the presence of simulated consolidation artifacts **804** may be determined based at least in part on the geometry of the approximate consolidation domains **400** and/or approximate consolidation boundaries **402**, and/or their respective configuration and arrangements, such as a hatch width and/or a layer height. As another example, the presence of simulated consolidation artifacts **804** may be determined based at least in part on an algebraic property corresponding to the approximate consolidation domains **400** and/or approximate consolidation boundaries **402**, and/or their respective configuration and arrangements. In some embodiments, the presence of simulated consolidation artifacts **804** may be determined based at least in part on a curve fitting algorithm, an algebraic fitting algorithm, and/or a geometric fitting algorithm. In some embodiments, a geometric shape, and/or a configuration and/or arrangement, of the approximate consolidation domains **400** may be determined from an irradiation parameter matrix **500**, and the presence of one or more simulated consolidation artifacts **804** may be determined based at least in part on the geometric shape, and/or the configuration and/or arrangement, of the plurality of approximate consolidation domains **400**.

[0106] By way of example, as shown in FIGS. **10**A-**10**C, a geometric shape, and/or a configuration and arrangement, of approximate consolidation domains **400** may yield one or more void elements **806** and/or one or more overlap elements **808**. Such void elements **806** may correspond to an increased probability for voids, pores, incomplete melting or sintering or non-sintered or non-melted powder material **120**, or the like in the three-dimensional object **114**. As shown in FIG. **10**B, in some embodiments, a geometric shape, and/or a configuration and arrangement, of approximate consolidation domains **400** may yield one or more overlap elements **808**, such as one or more overlap elements **808** with four overlapping approximate consolidation domains **400**. By way of example, four overlapping approximate consolidation domains **400** may correspond to an increased probability for vaporization, sputtering, or the like during additive manufacturing, for example, attributable to excessive local temperature and/or temperature gradient, which may cause voids, pores, or the like in the three-dimensional object **114**. As shown in FIG. **10**C, one or more void elements **806** may be attributable at least in part to variation in the geometric shape, and/or variation in the configuration and/or arrangement, of approximate consolidation domains **400**.

[0107] In some embodiments, a geometric shape, and/or a configuration and/or arrangement, of the approximate consolidation domains **400** may be determined based at least in part on a probability distribution. The probability distribution may be determined based at least in part on an irradiation parameter matrix **500**. For example, as shown in FIG. **10**C, a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800** may include at least some approximate consolidation domains **400** that differ from one another based at least in part on a probability distribution. The probability distribution may correspond to an irradiation parameter matrix **500**. The difference represented by the probability distribution may correspond to one or more dimensional properties, such as one or more geometric properties, one or more algebraic properties, and/or one or more statistical properties. The presence of one or more simulated consolidation artifacts **804**, such as void elements **806** and/or overlap elements **808**, may be determined based at least in part on the geometric shape, and/or the configuration and/or arrangement, of the plurality of approximate consolidation domains **400** determined from the probability distribution. A distribution of the quantity and/or size of one or more simulated consolidation artifacts **804**, such as void elements **806** and/or overlap elements **808**, may be determined, for example, by quantifying the presence of the simulated consolidation artifacts **804** determined based at least in part on the geometric shape, and/or the configuration and/or arrangement, of the plurality of approximate consolidation domains **400**. The simulated consolidation artifacts **804**, and/or the distribution thereof, may depend at least in part on the probability distribution for the approximate consolidation domains **400** by virtue of the geometric shape, and/or the configuration and/or arrangement, of the approximate consolidation domains **400** being determined based at least in part on the probability distribution.

[0108] Additionally, or in the alternative, in some embodiments, a probability distribution for one or more simulation artifacts, such as void elements **806** and/or overlap elements **808**, may be determined based at least in part on a probability for a geometric shape, and/or a probability for configuration and/or arrangement, of a plurality of approximate consolidation domains **400** in a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800**. For example, FIGS. **10**D and **10**E shows probability maps for a geometric shape, and/or a configuration and arrangement, of plurality of approximate consolidation domains **400**. The probability maps may represent a probable geometric shape, and/or a probable configuration and arrangement, of plurality of approximate consolidation domains **400**. The probability maps may be based at least in part on a statistical confidence interval or range, such as a statistical variance and/or a standard deviation. The presence of one or more simulated consolidation artifacts **804**, such as void elements **806** and/or overlap elements **808**, may be determined based at least in part on the probability of respective approximate consolidation domains **400** having one or more dimensional properties, such as one or more geometric properties, one or more algebraic properties, and/or one or more statistical properties. For example, the presence of one or more simulated consolidation artifacts **804** may be determined based at least in part on the probability of respective approximate consolidation domains **400** having a given geometric shape, and/or the probability of respective approximate consolidation domains **400** having a given configuration and/or arrangement. As another example, the presence of one or more simulated consolidation artifacts **804** may be determined based at least in part on the probability of respective approximate consolidation domains **400** corresponding to a given algebraic property, such being described by a given equation. Additionally, or in the alternative, the presence of one or more simulated consolidation artifacts **804** may be determined based at least in part on the probability of respective approximate consolidation domains **400** corresponding to a given statistical property, such as a probability distribution. In some embodiments, a probability distribution may be determined for one or more simulated consolidation artifacts **804** in the simulated additively manufactured three-dimensional object **800**, such as a probability distribution for the quantity and/or size of void elements **806** and/or overlap elements **808**. In some embodiments, a probability distribution for the presence of one or more simulated consolidation artifacts **804** may be determined with respect to a statistical variance or standard deviation. Additionally, or in the alternative, a probability distribution for the presence of one or more simulated consolidation artifacts **804** may be determined with respect to a 1-sigma variance, a 2-sigma variance, a 3-sigma variance, or any other desired statistical variance.

[0109] In some embodiments, the presence of a simulated consolidation artifacts **804**, such as a void element **806** and/or an overlap element **808**, may be determined at a given location when the probability of the simulated consolidation artifact **804** at the given location falls within a probability range. As shown in FIG. **10**D, a void element **806** may have a high probability of being present at a location as indicated. For example, a void element **806** may be present at the location indicated in FIG. **10**D when the corresponding approximate consolidation boundaries **402** are located inside the 3-sigma outward approximate consolidation boundaries **608**. The void element **806** may be present with a probability corresponding to the approximate consolidation boundaries **402** being located anywhere inside of the 3-sigma outward approximate consolidation boundaries **608**. Conversely, an overlap element **808** may have a low probability of being present at a location as indicated. For example, an overlap element may be present at the location indicated in FIG. **10**D when the corresponding approximate consolidation boundaries are located at the 3-sigma outward approximate consolidation boundaries **608** or further outward from the 3-sigma outward approximate consolidation boundaries **608**. The overlap element **808** may be present with a probability corresponding to the approximate consolidation boundaries **402** being located at or outward from the 3-sigma outward approximate consolidation boundaries **608**. In some embodiments, the probability of an overlap element **808** being located at a given position may be inversely proportional to the probability of a void element **806** being located at the given position, or vice versa.

[0110] As shown in FIG. **10**E, a void element **806** may have a low probability of being present at a location as indicated. For example, a void element **806** may be present at the location indicated in FIG. **10**D when the corresponding approximate consolidation boundaries **402** are located outside of the respective range defined by the respective 2-sigma outward approximate consolidation boundary **604** and the 2-sigma inward approximate consolidation boundary **606**. The void element **806** may be present with a probability corresponding to the respective approximate consolidation boundaries **402** being located between the respective 2-sigma outward approximate consolidation boundary **604** and the 2-sigma inward approximate consolidation boundary **606**. Conversely, an overlap element **808** may have a high probability of being present at a location as indicated. For example, an overlap element may be present at the location indicated in FIG. **10**D when the corresponding approximate consolidation boundaries are located at a location from the respective 2-sigma outward approximate consolidation boundary **604** and the 2-sigma inward approximate consolidation boundary **606**. The overlap element **808** may be present with a probability corresponding to the approximate consolidation boundaries **402** being located from the respective 2-sigma outward approximate consolidation boundary **604** to the 2-sigma inward approximate consolidation boundary **606**. In some embodiments, the probability of an overlap element **808** being located at a given position may be inversely proportional to the probability of a void element **806** being located at the given position, or vice versa.

[0111] In some embodiments, one or more material properties of an actually additively manufactured object **114** may be determined based at least in part on a simulated additively manufactured three-dimensional object **800**. A correlation may be determined between one or more material properties and a geometric shape of a plurality of approximate consolidation domains **400** and/or a configuration and arrangement of a plurality of approximate consolidation domains **400** in a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800**. The correlation may be determined based at least in part on data from an irradiation parameter matrix **500**. In some embodiments, a value for one or more material properties may be determined and/or predicted with reference to a probability, for example, based at least in part on the irradiation parameter matrix **500** and/or a simulated additively manufactured three-dimensional object **800**. For example, a statistical inference may be determined for one or more material properties based at least in part on the irradiation parameter matrix **500** and/or a simulated additively manufactured three-dimensional object **800**. Additionally, or in the alternative, a predictive inference may be determined for an additively manufactured object **114** that may be additively manufactured based at least in part on the simulated additively manufactured three-dimensional object **800**. Exemplary material properties for which a statistical inference and/or a predictive inference may be determined include porosity, void sizes, void areas, void aspect ratios, density, elastic modulus, and the like. Further exemplary material properties for which a statistical inference and/or a predictive inference may be determined include grain structures and/or crystalline structures, such as coarse grain regions, microcrystalline grain regions, nanocrystalline grain regions, amorphous regions, precipitates, crystalline dislocations, twinning dislocations, and the like. Further exemplary material properties for which a statistical inference and/or a predictive inference may be determined include unmelted powder particles, unsintered powder particles, unbound binder particles, and the like.

[0112] Now turning to FIG. **11**, an exemplary computing system **1100** will be described. The computing system **1100** may be included as part of an additive manufacturing machine **102** or additive manufacturing system **100**, or the computing system **1100** may be separately or remotely located from an additive manufacturing machine **102** or additive manufacturing system **100**. The computing system **1100** may be included as part of, or provided separately from, a control system **104** used to control an additive manufacturing machine **102** or additive manufacturing system **100**. Regardless of where the computing system **1100** may be implemented, the computing system **1100** may be configured to perform one or more control operations. The computing system **1100** may be configured to perform one or more additive manufacturing simulations, including generating a simulated additively manufactured three-dimensional object **800**, determining a statistical inference for one or more dimensional properties of the simulated additively manufactured three-dimensional object **800**, and/or determining a predictive inference one or more material properties of an additively manufactured three-dimensional object **114** that may be manufactured based at least in part on the simulated additively manufactured three-dimensional object **800**. The computing system **1100** may be configured to determine simulated consolidation artifacts **804** in a simulated consolidation layer **802** and/or a simulated additively manufactured three-dimensional object **800**, such as void elements **806** and/or overlap elements **808**. The predictive inference of the one or more material properties of the additively manufactured three-dimensional object **114** may be determined by the computing system **1100** based at least in part on one or more simulated consolidation artifacts **804**.

[0113] A control system **104** and/or the computing system **1100** may be configured to output one or more control commands associated with an additive manufacturing machine **102**. For example, a control system **104** may be configured to utilize the computing system **1100**. The control commands may be configured to control one or more controllable components of an additive manufacturing machine **102**. For example, the control system **104** may be configured to additively manufacture a three-dimensional object **114** based at least in part on an additive manufacturing simulation.

[0114] The computing system **1100** may be configured to generate a CAD file that includes a computer generated model of an object based at least in part on a simulated additively manufactured three-dimensional object **800**. Additionally, or in the alternative, the computing system **1100** may be configured to generate a build file for additively manufacturing a three-dimensional object **114** based at least in part on a simulated additively manufactured three-dimensional object **800**. The build file may include instructions based upon which the computing system **1100** may output control commands to an additive manufacturing machine **102** to additively manufacture the three-dimensional object **114**. The control commands may be configured to cause the additive manufacturing machine to direct one or more energy beams to specified locations of a build plane **130** for selectively solidifying respective layers of an object **114**. Additionally, or in the alternative, the control commands may include setpoints for one or more irradiation parameters, such as power, intensity, intensity profile, power density, spot size, spot shape, scanning pattern, scanning speed, and so forth. In some embodiments, the computing system **1100** may be configured to determine one or more setpoints for one or more irradiation parameters based at least in part on an additive manufacturing simulation and/or a simulated additively manufactured three-dimensional object **800**.

[0115] In some embodiments, a computing system **1100** may be configured to determine one or more digital representations **200**, such as one or more micrographic images **201** of a three-dimensional object **114**. Additionally, or in the alternative, a computing system **1100** may be configured to perform an additive manufacturing simulation based at least in part on the one or more digital representations **200**, such as the one or more micrographic images **201**. The computing system **1100** may be configured to determine one or more consolidation tracks **202**, such as for a consolidation boundary **300**, in a digital representation **200**, such as a micrographic image **201**, of a three-dimensional object **114**. Additionally, or in the alternative, the control system may be configured to determine an approximate consolidation domain **400** corresponding to a consolidation track **202**.

[0116] In some embodiments, a computing system **1100** may be configured to determine an irradiation parameter matrix **500**, and/or to determine on one or more statistical parameters based at least in part on data from an irradiation parameter matrix **500**. The computing system **1100** may be configured to determine one or more probability maps of approximate consolidation domains **400**, for example, based at least in part on data from an irradiation parameter matrix **500**. Additionally, or in the alternative, a computing system **1100** may be configured to determine one or more dimensional properties of a consolidation track **202** and/or of an approximate consolidation domain **400**, such as a distribution of probable values for a given dimensional property.

[0117] As shown in FIG. **11**, an exemplary computing system **1100** may include one or more control modules **1102** configured to cause the computing system **1100** to perform one or more control operations. The one or more control modules **1102** may include control logic executable to perform one or more operations assigned to the respective control module **1102**.

[0118] For example, the one or more control modules **1102** may include an additive manufacturing simulation module **1200**. An additive manufacturing simulation module **1200** may be configured as described herein with reference to FIG. **12**. Additionally, or in the alternative, the one or more control modules **1102** may include an object design module **1400**. An object design module **1400** may be configured as described herein with reference to FIG. **14**. Additionally, or in the alternative, the one or more control modules **1102** may include an additive manufacturing module **1600**. An additive manufacturing module **1600** may be configured as described herein with reference to FIG. **16**.

[0119] The one or more control modules **1102** may include control logic executable to determine one or more irradiation parameters for an additive manufacturing machine **102**, such as setpoints for one or more irradiation parameters, including, by way of example, power, intensity, intensity profile, power density, spot size, spot shape, scanning pattern, scanning speed, and so forth. Additionally, or in the alternative, the one or more control modules **1102** may include control logic executable to provide control commands configured to control one or more controllable components associated with an additive manufacturing machine **102**, such as controllable components associated with an energy beam system **134** and/or a monitoring system **162**. For example, a control module **1102** may be configured to provide one or more control commands based at least in part on one or more setpoints for one or more irradiation parameters.

[0120] The computing system **1100** may be communicatively coupled with an additive manufacturing machine **102**. In some embodiments, the computing system **1100** may be communicatively coupled with one or more components of an additive manufacturing machine **102**, such as one or more components of an energy beam system **134**, and/or a monitoring system **162**. The computing system **1100** may also be communicatively coupled with a management system **106** and/or a user interface **108**.

[0121] The computing system **1100** may include one or more computing devices **1104**, which may be located locally or remotely relative to the additive manufacturing machine **102** and/or the monitoring system **162**. The one or more computing devices **1104** may include one or more processors **1106** and one or more memory devices **1108**. The one or more processors **1106** may include any suitable processing device, such as a microprocessor, microcontroller, integrated circuit, logic device, and/or other suitable processing device. The one or more memory devices **1108** may include one or more computer-readable media, including but not limited to non-transitory computer-readable media, RAM, ROM, hard drives, flash drives, and/or other memory devices **1108**.

[0122] As used herein, the terms “processor” and “computer” and related terms, such as “processing device” and “computing device”, are not limited to just those integrated circuits referred to in the art as a computer, but broadly refers to a microcontroller, a microcomputer, a programmable logic controller (PLC), an application specific integrated circuit, and other programmable circuits, and these terms are used interchangeably herein. A memory device **1108** may include, but is not limited to, a non-transitory computer-readable medium, such as a random access memory (RAM), and computer-readable nonvolatile media, such as hard drives, flash memory, and other memory devices. Alternatively, a floppy disk, a compact disc-read only memory (CD-ROM), a magneto-optical disk (MOD), and/or a digital versatile disc (DVD) may also be used.

[0123] As used herein, the term “non-transitory computer-readable medium” is intended to be representative of any tangible computer-based device implemented in any method or technology for short-term and long-term storage of information, such as, computer-readable instructions, data structures, program modules and sub-modules, or other data in any device. The methods described herein may be encoded as executable instructions embodied in a tangible, non-transitory, computer readable media, including, without limitation, a storage device and/or a memory device. Such instructions, when executed by a processor, cause the processor to perform at least a portion of the methods described herein. Moreover, as used herein, the term “non-transitory computer-readable medium” includes all tangible, computer-readable media, including, without limitation, non-transitory computer storage devices, including, without limitation, volatile and nonvolatile media, and removable and non-removable media such as a firmware, physical and virtual storage, CD-ROMs, DVDs, and any other digital source such as a network or the Internet, as well as yet to be developed digital means, with the sole exception being a transitory, propagating signal.

[0124] The one or more memory devices **1108** may store information accessible by the one or more processors **1106**, including computer-executable instructions **1110** that can be executed by the one or more processors **1106**. The instructions **1110** may include any set of instructions which when executed by the one or more processors **1106** cause the one or more processors **1106** to perform operations, including optical element monitoring operations, maintenance operations, cleaning operations, calibration operations, and/or additive manufacturing operations.

[0125] The memory devices **1108** may store data **1112** accessible by the one or more processors **1106**. The data **1112** can include current or real-time data **1112**, past data **1112**, or a combination thereof. The data **1112** may be stored in a data library **1114**. As examples, the data **1112** may include data **1112** associated with or generated by an additive manufacturing system **100** and/or an additive manufacturing machine **102**, including data **1112** associated with or generated by the computing system **1100**, an additive manufacturing machine **102**, an energy beam system **134**, a monitoring system **162**, a management system **106**, a user interface **108**, and/or a computing device **1104**. In some embodiments, the data **1112** may include data **1112** associated with one or more digital representations **200** (such as one or more micrographic images **201**), data **1112** associated with an irradiation parameter matrix **500**, and/or data associated with a simulated additively manufactured three-dimensional object **800**, and/or data **1112** associated with an additive manufacturing simulation. Additionally, or in the alternative, the data **1112** may pertain to operation of an energy beam system **134** and/or a monitoring system **162**. The data **1112** may also include other data sets, parameters, outputs, information, associated with an additive manufacturing system **100** and/or an additive manufacturing machine **102**.

[0126] The one or more computing devices **1104** may also include a communication interface **1116**, which may be used for communications with a communication network **1118** via wired or wireless communication lines **1120**. The communication interface **1116** may include any suitable components for interfacing with one or more network(s), including for example, transmitters, receivers, ports, controllers, antennas, and/or other suitable components. The communication interface **1116** may allow the computing device **1104** to communicate with various nodes on the communication network **1118**, such as nodes associated with the additive manufacturing machine **102**, the energy beam system **134**, the monitoring system **162**, the management system **106**, and/or a user interface **108**. The communication network **1118** may include, for example, a local area network (LAN), a wide area network (WAN), SATCOM network, VHF network, a HF network, a Wi-Fi network, a WiMAX network, a gatelink network, and/or any other suitable communication network **1118** for transmitting messages to and/or from the computing system **1100** across the communication lines **1120**. The communication lines **1120** of communication network **1118** may include a data bus or a combination of wired and/or wireless communication links.

[0127] The communication interface **1116** may allow the computing device **1104** to communicate with various components of an additive manufacturing system **100** and/or an additive manufacturing machine **102** communicatively coupled with the communication interface **1116** and/or communicatively coupled with one another, including an energy beam system **134** and/or a monitoring system **162**. The communication interface **1116** may additionally or alternatively allow the computing device **1104** to communicate with the management system **106** and/or the user interface **108**. The management system **106** may include a server **1122** and/or a data warehouse **1124**. As an example, at least a portion of the data **1112** may be stored in the data warehouse **1124**, and the server **1122** may be configured to transmit data **1112** from the data warehouse **1124** to the computing device **1104**, and/or to receive data **1112** from the computing device **1104** and to store the received data **1112** in the data warehouse **1124** for further purposes. The server **1122** and/or the data warehouse **1124** may be implemented as part of a computing system **1100**, as part of a control system **104**, and/or as part of the management system **106**.

[0128] FIG. **12** schematically depicts an exemplary additive manufacturing simulation module **1200**. An additive manufacturing simulation module **1200** may be configured to perform an additive manufacturing simulation. An additive manufacturing simulation module **1200** may be implemented by a computing system **1100** provides as part of, or provided separately from, an additive manufacturing machine **102** or additive manufacturing system **100**. For example, a computing system **1100** used to perform an additive manufacturing simulation may be separate from, or integrated with, a control system **104** associated with an additive manufacturing machine **102** and/or associated with an additive manufacturing system **100**.

[0129] As shown in FIG. **12**, an additive manufacturing simulation module **1200** may be configured to perform an additive manufacturing simulation based at least in part on consolidation specimen data **1202**. The consolidation specimen data **1202** may include one or more digital representations **200**, such as one or more micrographic images **201**, of one or more three-dimensional objects **114** and/or data pertaining thereto. The additive manufacturing simulation data **1204** may include a simulated additively manufactured three-dimensional object **800**. The additive manufacturing simulation performed by the additive manufacturing simulation module **1200** may include outputting additive manufacturing simulation data **1204**. For example, the additive manufacturing simulation data **1204** may be output to an object design module as described herein with reference to FIG. **14** and/or an additive manufacturing module as described herein with reference to FIG. **16**.

[0130] In some embodiments, an additive manufacturing simulation module **1200** may include a digital representation module **1206**, such as a micrographic imaging module. The digital representation module **1206** may be configured to determine the consolidation specimen data **1202**, for example, as described with reference to FIG. **2**. The consolidation specimen data **1202** may be stored in a data library **1114** and/or a data warehouse **1124** as described with reference to FIG. **11**. Additionally, or in the alternative, the digital representation module **1206** may be configured to cause an imaging system **203** to acquire consolidation specimen data **1202**, such as one or more digital representations **200** (e.g., micrographic images **201**) of a three-dimensional object **114** and/or data **1112** pertaining thereto. The digital representation module **1206** may be configured to cause the imaging system **203** to provide the consolidation specimen data **1202** for use in one or more operations performed by the digital representation module **1206**.

[0131] In some embodiments, an additive manufacturing simulation module **1200** may include a consolidation domain module **1208**. The consolidation domain module **1208** may be configured to determine one or more consolidation tracks **202**, such as for corresponding consolidation boundaries **300**, for example, as described with reference to FIGS. **3**A-**3**C. The consolidation domain module **1208** may determine the one or more consolidation tracks **202** from consolidation specimen data **1202** and/or from one or more digital representations **200**, such as one or more micrographic images **201**. Additionally, or in the alternative, consolidation domain module **1208** may be configured to determine one or more approximate consolidation domains **400** and/or one or more approximate consolidation boundaries **402**, for example, as described with reference to FIGS. **4**A-**4**C. The consolidation domain module **1208** may determine the one or more approximate consolidation domains **400** and/or the one or more approximate consolidation boundaries **402** from the consolidation specimen data **1202** and/or from the one or more digital representations **200** (e.g., micrographic images **201**). The one or more approximate consolidation domains **400** and/or corresponding approximate consolidation boundaries **402** may respectively correspond to the one or more consolidation tracks **202** and/or corresponding consolidation boundaries **300**.

[0132] In some embodiments, an additive manufacturing simulation module **1200** may include an experimental design module **1210**. The experimental design module **1210** may be configured to determine an experimental design for generating data for an additive manufacturing simulation. In some embodiments, the experimental design module **1210** may be configured to develop an irradiation parameter matrix **500**, for example, as described with reference to FIG. **5**. For example, the experimental design module **1210** may be configured to determine a plurality of nodes **502** that define respective irradiation parameter values to be utilized when forming the consolidation track **202** corresponding to the respective node **502**. The experimental design module **1210** may be configured to cause an additive manufacturing machine **102** to additively manufacture three-dimensional objects **114** corresponding to the experimental design and/or the irradiation parameter matrix **500**.

[0133] In some embodiments, an additive manufacturing simulation module **1200** may include a statistical analysis module **1212**. The statistical analysis module **1212** may be configured to determine one or more statistical parameters corresponding to additively manufactured three-dimensional objects **114** and/or simulated additively manufactured three dimensional objects **800**. For example, the statistical analysis module **1212** may determine one or more statistical parameters based at least in part on data from an irradiation parameter matrix **500**. Additionally, or in the alternative, the statistical analysis module **1212** may determine one or more statistical inferences based at least in part on data from an irradiation parameter matrix **500**. In some embodiments, the statistical analysis module **1212** may determine probability maps of approximate consolidation domains **400** as described herein with reference to FIGS. **6**A-**6**C. Additionally, or in the alternative, the statistical analysis module **1212** may determine one or more dimensional properties of consolidation tracks **202** and/or approximate consolidation domains **400**, such as a statistical inference with respect thereto, as described herein with reference to FIGS. **7**A-**7**C.

[0134] In some embodiments, the statistical analysis module **1212** may determine a probability distribution for a geometric shape, and/or for a configuration and/or arrangement, of the approximate consolidation domains **400**, for example, as described herein with reference to FIGS. **8**A-**8**E, **9**A-**9**D, and **10**A-**10**E. In some embodiments, the statistical analysis module **1212** may determine a probability distribution of one or more simulated consolidation artifacts **804**, for example, as described herein with reference to FIG. **8**E. Additionally, or in the alternative, the statistical analysis module **1212** may determine a probability distribution for at least some approximate consolidation domains **400** that differ from one another based at least in part on, for example, as described herein with reference to FIG. **10**C. Additionally, or in the alternative, the statistical analysis module **1212** may determine one or more probability maps for a geometric shape, and/or a configuration and arrangement, of plurality of approximate consolidation domains **400**, for example, as described with reference to FIGS. **10**D and **10**E.

[0135] In some embodiments, an additive manufacturing simulation module **1200** may include an object simulation module **1214**. The object simulation module **1214** may be configured to generate a simulated an additively manufactured three-dimensional object **800**, for example, as described herein with reference to FIGS. **8**A-**8**E, **9**A-**9**D, and **10**A-**10**E. The object simulation module **1214** may generate a simulated an additively manufactured three-dimensional object **800** using one or more of the modules described herein, such as one or more of the modules described with reference to the additive manufacturing simulation module **1200**. In some embodiments, the object simulation module **1214** may determine one or more dimensional properties of, and/or a configuration and arrangement of, simulated consolidation layers **802**, as described, for example, with reference to FIGS. **8**A-**8**C and **9**A-**9**D. Additionally, or in the alternative, an object simulation module **1214** may determine one or more dimensional properties of, and/or a configuration and arrangement of, approximate consolidation domains **400** included in respective simulated consolidation layers **802**, for example, using a computer vision program as described herein. Additionally, or in the alternative, an object simulation module **1214** may determine one or more simulation simulated consolidation artifacts **804**, for example, using a computer vision program as described herein.

[0136] In some embodiments, an additive manufacturing simulation module **1200** may include a predictive inference module **1216**. The predictive inference module **1216** may be configured to determine a predictive inference of one or more material properties of a three-dimensional object **114** that may be additively manufactured based at least in part on a simulated additively manufactured three-dimensional object **800**. For example, the predictive inference module **1216** may determine a predictive inference as to porosity, void sizes, void area, void aspect ratio, void maximum size, density, elastic modulus, yield strength, ductility, hardness, surface finish, mass, fatigue limit, creep, and the like. Additionally, or in the alternative, exemplary material properties for which a predictive inference module **1216** may determine a predictive inference include grain structures and/or crystalline structures of a three-dimensional object **114** that may be additively manufactured based at least in part on a simulated additively manufactured three-dimensional object **800**. Exemplary grain structures and/or crystalline structures for which a predictive inference may be determined include coarse grain structures, microcrystalline grain structures, nanocrystalline grain structures, amorphous regions, precipitates, crystalline dislocations, twinning dislocations, and the like. Further exemplary material properties for which a predictive inference module **1216** may determine a predictive inference include unmelted powder particles, unsintered powder particles, unbound binder particles, and the like.

[0137] In some embodiments, an additive manufacturing simulation module **1200** may include an object configuration module **1218**. An object configuration module **1218** may be configured to determine an object configuration, such as one or more dimensional properties, of an object **114** to be simulated in an additive manufacturing simulation and/or in a simulated additively manufactured three-dimensional object **800**. For example, an object configuration module **1218** may determine an object configuration from a CAD file for an object. Additionally, or in the alternative, an object configuration module **1218** may determine an object configuration from an object design module **1400** as described herein with reference to FIG. **14**.

[0138] Now turning to FIG. **13**, an exemplary method **1300** of simulating additively manufacturing a three-dimensional object will be described. Exemplary methods **1300** of simulating additively manufacturing a three-dimensional object may be performed using an additive manufacturing simulation module **1200**. Exemplary methods **1300** of simulating additively manufacturing a three-dimensional object may include any one or more operations for which an additive manufacturing simulation module **1200** may be configured. In some embodiments, an exemplary method **1300** may include, at block **1302**, determining a plurality of consolidation tracks **202** from a digital representation **200** of an additively manufactured three-dimensional object **114**. At block **1304**, an exemplary method **1300** may include determining a plurality of approximate consolidation domains **400** respectively corresponding to the plurality of consolidation tracks **400**. An exemplary method **1300** may include, at block **1306**, generating a simulated additively manufactured three-dimensional object **800** based at least in part on the plurality of approximate consolidation domains

**400**. At block **1308**, an exemplary method **1300** may include determining one or more material properties of a three-dimensional object **114** to be additively manufactured based at least in part on the simulated additively manufactured three-dimensional object.

[0139] An exemplary method **1300** may include designing a three-dimensional object to be additively manufactured, for example, as described with reference to FIG. **15**. In some embodiments, the three-dimensional object may be designed based at least in part on a simulated additively manufactured three-dimensional object and/or based at least in part on one or more predictive inferences with respect to one or more material properties of the three-dimensional object to be additively manufactured. Additionally, or in the alternative, an exemplary method **1300** may include additively manufacturing a three-dimensional object, for example, as described with reference to FIG. **17**. In some embodiments, the three-dimensional object may be additively manufactured based at least in part on a simulated additively manufactured three-dimensional object and/or based at least in part on one or more predictive inferences with respect to one or more material properties of the three-dimensional object to be additively manufactured.

[0140] Referring now to FIG. **14**, an exemplary object design module **1400** will be described. An object design module **1400** may be configured to perform one or more operations associated with designing an object **114** to be additively manufactured.

[0141] An object design module **1400** may be implemented by a computing system **1100** provides as part of, or provided separately from, an additive manufacturing machine **102** or additive manufacturing system **100**. For example, a computing system **1100** used to perform one or more operations associated with designing an object **114** to be additively manufactured may be separate from, or integrated with, a control system **104** associated with an additive manufacturing machine **102** and/or associated with an additive manufacturing system **100**.

[0142] As shown in FIG. **14**, an object design module **1400** may be configured to generate object design data **1402**. The object design data **1402** may be generated based at least in part on additive manufacturing simulation data **1204**. The additive manufacturing simulation data **1204** may be determined from a data library **1114** and/or a data warehouse **1124**. Additionally, or in the alternative, the additive manufacturing simulation data **1204** may be determined from an additive manufacturing simulation module **1200**.

[0143] In some embodiments, an object design module **1400** may include a CAD module **1404**. An exemplary CAD module **1404** may be configured to generate a CAD file that includes a CAD model of an object **114** to be additively manufactured. The object design data **1402** may include one or more CAD files and/or one or more CAD models generated by the CAD module **1404**. A CAD file and/or a CAD model may be generated by the CAD module **1404** based at least in part on additive manufacturing simulation data **1204**. For example, a CAD file and/or a CAD model may be generated by the CAD module **1404** based at least in part on a simulated additively manufactured three-dimensional object **800**. The CAD file may include one or more CAD models that provide a three-dimensional representation of an object **114** to be additively manufactured based at least in part on a simulated additively manufactured three-dimensional object **800**. In some embodiments, a simulated additively manufactured three-dimensional object **800** may be determined based at least in part on an initial CAD file that includes one or more initial CAD model for an object **114** to be additively manufactured. Additionally, or in the alternative, an initial CAD file and/or an initial CAD model may be augmented based at least in part on a simulated additively manufactured three-dimensional object **800**. For example, an augmented CAD file and/or an augmented CAD model may be generated from an initial CAD file and/or an initial CAD model based at least in part on a simulated additively manufactured three-dimensional object **800**.

[0144] In some embodiments, an object design module **1400** may include a slicing module **1406**. An exemplary slicing module **1406** may be configured to generate a build file that defines build instructions for an additive manufacturing machine to additively manufacture a three-dimensional object **114**. The build instructions may include slicing data, such as data that defines a plurality of slices collectively representing a three-dimensional object **114** and/or a plurality of slicing parameters pertaining thereto. Additionally, or in the alternative, the build instructions may include irradiation parameters for irradiating respective layers of powder material **120** to additively manufacture the three-dimensional object **114**. The plurality of slices may correspond to respective layers of powder material. The irradiation parameters may include, by way of example, power, intensity, intensity profile, power density, spot size, spot shape, scanning pattern, scanning speed, and so forth.

[0145] The object design data **1402** may include one or more build files generated by the slicing module **1406**. A build file may be generated by the slicing module **1406** based at least in part on additive manufacturing simulation data **1204**. Additionally, or in the alternative, a build file may be generated by the slicing module **1406** based at least in part on a CAD file and/or a CAD model, such as a CAD file and/or a CAD model generated by the CAD module **1404**. A build file may be generated by the slicing module **1406** based at least in part on a simulated additively manufactured three-dimensional object **800**. The build file may include one or more build instructions, including, for example, slicing data and/or irradiation parameters, for additively manufacturing a three-dimensional object **114** based at least in part on a simulated additively manufactured three-dimensional object **800**. In some embodiments, a simulated additively manufactured three-dimensional object **800** may be determined based at least in part on an initial build file that includes slicing data and/or irradiation parameters for an object **114** to be additively manufactured. Additionally, or in the alternative, an initial build file may be augmented based at least in part on a simulated additively manufactured three-dimensional object **800**. For example, an augmented build file may be generated from an initial build file based at least in part on a simulated additively manufactured three-dimensional object **800**. The augmented build file may include, for example, augmented slicing data and/or augmented irradiation parameters determined, for example, based at least in part on a simulated additively manufactured three-dimensional object **800**.

[0146] Now turning to FIG. **15**, exemplary method **1500** of designing a three-dimensional object **114** to be additively manufactured will be described. Exemplary methods **1500** of designing a three-dimensional object **114** may be performed using an object design module **1400**. Exemplary methods **1500** of designing a three-dimensional object may include any one or more operations for which an object design module **1400** may be configured. In some embodiments, an exemplary method **1500** may include, at block **1502**, generating a CAD file and/or a build file for a three-dimensional object to be additively manufactured. The CAD file and/or the build file may be based at least in part on a simulated additively manufactured three-dimensional object **800**. Additionally, or in the alternative, the CAD file and/or the build file may be based at least in part on a predictive inference with respect to one or more material properties of the three-dimensional object.

[0147] In some embodiments, an exemplary method **1500** may include, at block **1504**, additively manufacturing one or more test specimen of the three-dimensional object based at least in part on the CAD file and/or the build file. The one or more test specimen may be additively manufactured using one or more different additive manufacturing machines **102** and/or additive manufacturing systems **100**. For example, the one or more test specimen may be additively manufactured at least in part to determine whether an additive manufacturing machine **102** and/or additive manufacturing system **100** yields an additively manufactured three-dimensional object **114** with one or more material properties that are as expected and/or suitable, such as with respect to one or more quality and/or productivity metrics. Additionally, or in the alternative, the one or more test specimen may be additively manufactured using one or more different irradiation devices **138**, **140** and/or one or more different energy beams **142**, **148** with respect to all or a portion of a respective test specimen, for example, to determine whether the respective irradiation devices **138**, **140** and/or energy beams **142**, **148** yields an additively manufactured three-dimensional object **114** with one or more material properties that are as expected and/or suitable, such as with respect to one or more quality and/or productivity metrics.

[0148] At block **1506**, an exemplary method **1500** may include determining one or more material properties of the one or more test specimen and/or comparing the one or more material properties of the one or more test specimen to respective ones of the one or more predictive inferences with respect to the one or more material properties of the three-dimensional object. For example, at block **1508**, an exemplary method may include determining whether the one or more material properties of the one or more test specimen sufficiently match the respective ones of the one or more predictive inferences. At block **1510**, when the one or more material properties sufficiently match the respective ones of the one or more predictive inferences, an exemplary method **1500** may include designating the CAD file and/or the build file as ready for manufacturing and/or providing the CAD file and/or the build file to an additive manufacturing machine, such as to additively manufacture the three-dimensional object **114**.

[0149] When the one or more material properties do not sufficiently match the respective ones of the one or more predictive inferences at block **1508**, an exemplary method **1500** may include, at block **1512**, revising and/or updating an additive manufacturing simulation. Revising and/or updating an additive manufacturing simulation may include generating a revised and/or updated simulated additively manufactured three-dimensional object and/or determining a revised and/or updated predictive inference with respect to one or more material properties of a three-dimensional object to be additively manufactured based at least in part on the revised and/or updated simulated additively manufactured three-dimensional object. Additionally, or in the alternative, when the one or more material properties do not sufficiently match the respective ones of the one or more predictive inferences at block **1508**, an exemplary method **1500** may return to block **1502**, and generate a revised CAD file and/or build file for the three-dimensional object to be additively manufactured. The revised CAD file and/or the revised build file may be based at least in part on the one or more material properties of the one or more test specimen. Additionally, or in the alternative, the revised CAD file and/or the revised build file may be based at least in part on the comparison of the one or more material properties of the one or more test specimen to respective ones of the one or more predictive inferences.

[0150] In some embodiments, an exemplary method **1500** may include additively manufacturing a three-dimensional object, for example, as described with reference to FIG. **17**. The three-dimensional object may be additively manufactured based at least in part on a simulated additively manufactured three-dimensional object and/or based at least in part on one or more predictive inferences with respect to one or more material properties of the three-dimensional object to be additively manufactured.

[0151] Now turning to FIG. **16**, an exemplary additive manufacturing module **1600** will be described. An additive manufacturing module **1600** may be configured to perform one or more additive manufacturing operations using an additive manufacturing machine **102**. For example, as shown in FIG. **16**, an additive manufacturing module **1600** may be configured to generate control commands for an additive manufacturing machine **102**, such as to additively manufacture a three-dimensional object **114**. The control commands may be generated based at least in part on object design data **1402** and/or based at least in part on additive manufacturing simulation data **1204**. The additive manufacturing module **1600** may be configured to generate additive manufacturing control commands **1602**.

[0152] In some embodiments, an additive manufacturing module **1600** may include an irradiation parameter module **1604**. An irradiation parameter module **1604** may be configured to determine one or more irradiation parameters for additively manufacturing a three-dimensional object **114**. Additionally, or in the alternative, an irradiation parameter module **1604** may be configured to generate additive manufacturing control commands **1602**, such as control commands configured to control the one or more irradiation parameters for additively manufacturing the three-dimensional object **114**. Exemplary irradiation parameters that may be determined and/or controlled may include, by way of example, power, intensity, intensity profile, power density, spot size, spot shape, scanning pattern, scanning speed, and so forth.

[0153] In some embodiments, an additive manufacturing module **1600** may include an irradiation regime module **1606**. An irradiation regime module **1606** may be configured to determine an irradiation regime for additively manufacturing the three-dimensional object **114**. For example, an irradiation regime module **1606** may determine an allocation of one or more three-dimensional objects **114**, and/or one or more regions thereof, as between respective ones of a plurality of irradiation devices **138**, **140** and/or as between respective ones of a plurality of energy beams **142**, **148**.

[0154] Now turning to FIG. **17**, exemplary methods **1700** of additively manufacturing a three-dimensional object will be described. Exemplary methods **1700** of additively manufacturing a three-dimensional object may be performed using an additive manufacturing module **1600**. Exemplary methods **1700** of additively manufacturing a three-dimensional object **114** may include any one or more operations for which an additive manufacturing module **1600** may be configured. In some embodiments, an exemplary method **1700** may include, at block **1702**, generating a simulated additively manufactured three-dimensional object **800** based at least in part on a plurality of approximate consolidation domains **400**. The plurality of approximate consolidation domains **400** may respectively correspond to a plurality of consolidation tracks **202** determined from one or more digital representations **200**, such as micrographic images **201**, of an additively manufactured three-dimensional object **114**. At block **1704**, an exemplary method **1700** may include determining a predictive inference with respect to one or more material properties of the three-dimensional object **114** to be additively manufactured. The predictive inference may be based at least in part on the simulated additively manufactured three-dimensional object **800**. Additionally, or in the alternative, at block **1706**, an exemplary method **1700** may include generating a CAD file and/or a build file for the three-dimensional object **114** to be additively manufactured. The CAD file and/or the build file may be based at least in part on the simulated additively manufactured three-dimensional object **800** and/or based at least in part on one or more predictive inferences with respect to one or more material properties of the three-dimensional object **114** to be additively manufactured. The exemplary method **1700** may include, at block **1708**, additively manufacturing the three-dimensional object **114** based at least in part on the simulated additively manufactured three-dimensional object **800**. Additionally, or in the alternative, block **1708** may include additively manufacturing the three-dimensional object **114** based at least in part on the predictive inference. Additionally, or in the alternative, block **1708** may include additively manufacturing the three-dimensional object **114** based at least in part on the CAD file and/or the build file.

[0155] Further aspects of the invention are provided by the subject matter of the following clauses:

[0156] 1. A method of simulating additively manufacturing a three-dimensional object, the method comprising: generating a simulated additively manufactured three-dimensional object based at least in part on a plurality of approximate consolidation domains, the plurality of approximate consolidation domains respectively corresponding to a plurality of consolidation tracks determined from one or more digital representations of an additively manufactured three-dimensional object; and determining a predictive inference with respect to one or more material properties of a three-dimensional object to be additively manufactured based at least in part on the simulated additively manufactured three-dimensional object.

[0157] 2. The method of any clause herein, comprising: determining the plurality of approximate consolidation domains based at least in part on the plurality of consolidation tracks.

[0158] 3. The method of any clause herein, comprising: determining the plurality of approximate consolidation domains based at least in part on a curve fitting algorithm and/or based at least in part on a data library that includes a plurality of geometric approximation candidates.

[0159] 4. The method of any clause herein, comprising: selecting a geometric approximation candidate from among the plurality included in the data library based at least in part on a comparison of one or more of the plurality of geometric approximation candidates to one or more

of the plurality of approximate consolidation domains.
[0160] 5. The method of any clause herein, comprising: determining the plurality of approximate consolidation domains based at least in part on a geometric approximation candidate selected from the data library using a comparison algorithm.
[0161] 6. The method of any clause herein, wherein the plurality of consolidation tracks correspond to a melt pool domain, a sintering domain, or a reaction domain.
[0162] 7. The method of any clause herein, wherein the plurality of approximate consolidation domains comprises an approximate consolidation boundary.
[0163] 8. The method of any clause herein, wherein the one or more digital representations comprises one or more micrographic images.
[0164] 9. The method of any clause herein, comprising: determining the plurality of consolidation tracks, wherein determining the plurality of consolidation tracks comprises determining a consolidation boundary corresponding to respective ones of the plurality of consolidation tracks.
[0165] 10. The method of any clause herein, wherein the consolidation boundary comprises a melt pool boundary.
[0166] 11. The method of any clause herein, wherein generating the simulated additively manufactured three-dimensional object comprises: determining a plurality of simulated consolidation layers respectively including at least some of the plurality of approximate consolidation domains.
[0167] 12. The method of any clause herein, comprising: determining the plurality of approximate consolidation domains based at least in part on an irradiation parameter matrix, the irradiation parameter matrix comprising a plurality of nodes, respective ones of the plurality of nodes defining one or more irradiation parameter values utilized when forming a corresponding one or more consolidation tracks.
[0168] 13. The method of any clause herein, wherein the plurality of approximate consolidation domains respectively comprise an approximate consolidation boundary, the approximate consolidation boundary representing a mean, a median, or a mode determined from the plurality of consolidation tracks with a statistical confidence level.
[0169] 14. The method of any clause herein, wherein at least some of the plurality of approximate consolidation domains differ from one another in respect of at least one dimensional property in accordance with a probability distribution determined based at least in part on the plurality of consolidation tracks.
[0170] 15. The method of any clause herein, comprising: determining a plurality of simulated consolidation artifacts in the simulated additively manufactured three-dimensional object based at least in part on one or more dimensional properties of the plurality of approximate consolidation domains.
[0171] 16. The method of any clause herein, wherein the plurality of simulated consolidation artifacts comprises void elements and/or overlap elements.
[0172] 17. The method of any clause herein, wherein the plurality of simulated consolidation artifacts comprises coarse grain structures, microcrystalline grain structures, nanocrystalline grain structures, amorphous regions, precipitates, crystalline dislocations, and/or twinning dislocations.
[0173] 18. The method of any clause herein, wherein the plurality of simulated consolidation artifacts comprises unmelted powder particles, unsintered powder particles, or unbound binder particles.
[0174] 19. The method of any clause herein, wherein the one or more dimensional properties comprises a geometric shape of at least some of the plurality of approximate consolidation domains, and/or wherein the one or more dimensional properties comprises a configuration and arrangement of at least some of the plurality of approximate consolidation domains.
[0175] 20. The method of any clause herein, wherein the one or more dimensional properties comprises an algebraic property of at least some of the plurality of approximate consolidation

domains.
[0176] 21. The method of any clause herein, wherein the one or more dimensional properties comprises a geometric shape and/or one or more dimensional properties corresponding to the geometric shape.
[0177] 22. The method of any clause herein, comprising: determining a plurality of simulated consolidation artifacts in the simulated additively manufactured three-dimensional object based at least in part on a probability of respective ones of at least some of the plurality of approximate consolidation domains having a given dimensional property.
[0178] 23. The method of any clause herein, wherein the plurality of simulated consolidation artifacts comprises void elements.
[0179] 24. The method of any clause herein, comprising: determining a probability distribution for the plurality of simulated consolidation artifacts in the simulated additively manufactured three-dimensional object.
[0180] 25. The method of any clause herein, comprising: determining a plurality of simulated consolidation artifacts in the simulated additively manufactured three-dimensional object; and determining the predictive inference with respect to at least one of the one or more material properties of the three-dimensional object based at least in part on the plurality of simulated consolidation artifacts.
[0181] 26. The method of any clause herein, wherein the one or more material properties comprises: porosity, void sizes, void area, void aspect ratio, void maximum size, density, elastic modulus, yield strength, ductility, hardness, surface finish, mass, fatigue limit, and/or creep.
[0182] 27. The method of any clause herein, wherein the one or more material properties comprises: one or more grain structures and/or one or more crystalline structures.
[0183] 28. The method of any clause herein, wherein the one or more grain structures and/or one or more crystalline structures comprises: a coarse grain region, a microcrystalline grain region, a nanocrystalline grain region, an amorphous region, precipitates, crystalline dislocations, and/or twinning dislocations.
[0184] 29. The method of any clause herein, wherein the one or more material properties comprises unmelted powder particles, unsintered powder particles, and/or unbound binder particles.
[0185] 30. The method of any clause herein, comprising: generating a CAD file and/or a build file for a three-dimensional object to be additively manufactured, the CAD file and/or the build file based at least in part on the simulated additively manufactured three-dimensional object and/or based at least in part on the predictive inference with respect to the one or more material properties of the three-dimensional object to be additively manufactured.
[0186] 31. The method of any clause herein, comprising: additively manufacturing a three dimensional object based at least in part on the simulated additively manufactured three-dimensional object and/or based at least in part on the predictive inference with respect to the one or more material properties of the three-dimensional object to be additively manufactured.
[0187] 32. A method of additively manufacturing a three-dimensional object, the method comprising: generating a simulated additively manufactured three-dimensional object based at least in part on a plurality of approximate consolidation domains, the plurality of approximate consolidation domains respectively corresponding to a plurality of consolidation tracks determined from one or more digital representations of an additively manufactured three-dimensional object; and additively manufacturing a three-dimensional object based at least in part on the simulated additively manufactured three-dimensional object.
[0188] 33. The method of any clause herein, comprising: determining a predictive inference with respect to one or more material properties of the three-dimensional object to be additively manufactured based at least in part on the simulated additively manufactured three-dimensional object; additively manufacturing the three-dimensional object based at least in part on the predictive inference.

[0189] 34. The method of any clause herein, comprising: generating a CAD file and/or a build file for the three-dimensional object to be additively manufactured, the CAD file and/or the build file based at least in part on the simulated additively manufactured three-dimensional object and/or based at least in part on one or more predictive inferences with respect to one or more material properties of the three-dimensional object to be additively manufactured; and additively manufacturing the three-dimensional object based at least in part on the CAD file and/or the build file.

[0190] 35. A computer-readable medium comprising computer-executable instructions, which when executed by a processor, cause the processor to perform a method of designing an additively-manufactured three-dimensional object, the method comprising: generating a CAD file and/or a build file for a three-dimensional object to be additively manufactured, the CAD file and/or the build file based at least in part on a simulated additively manufactured three-dimensional object and/or based at least in part on one or more predictive inferences with respect to one or more material properties of the three-dimensional object to be additively manufactured; and additively manufacturing a three-dimensional object based at least in part on the CAD file and/or the build file.

[0191] 36. The computer-readable medium of any clause herein, wherein additively manufacturing the three-dimensional object based at least in part on the CAD file and/or the build file comprises: additively manufacturing one or more test specimen of the three-dimensional object based at least in part on the CAD file and/or the build file.

[0192] 37. The computer-readable medium of any clause herein, comprising: determining one or more material properties of the one or more test specimen and/or comparing the one or more material properties of the one or more test specimen to respective ones of the one or more predictive inferences with respect to the one or more material properties of the three-dimensional object.

[0193] 38. The computer-readable medium of any clause herein, comprising: designating the CAD file and/or the build file as ready for manufacturing and/or providing the CAD file and/or the build file to an additive manufacturing machine when the one or more material properties of the one or more test specimen sufficiently match respective ones of the one or more predictive inferences.

[0194] 39. The computer-readable medium of any clause herein, comprising: revising and/or updating an additive manufacturing simulation when the one or more material properties of the one or more test specimen do not sufficiently match respective ones of the one or more predictive inferences.

[0195] 40. The computer-readable medium of any clause herein, wherein revising and/or updating an additive manufacturing simulation comprises: generating a simulated additively manufactured three-dimensional object based at least in part on a plurality of approximate consolidation domains, the plurality of approximate consolidation domains respectively corresponding to a plurality of consolidation tracks determined from one or more digital representations of an additively manufactured three-dimensional object; and determining an updated predictive inference with respect to at least some of the one or more material properties of the three-dimensional object to be additively manufactured based at least in part on the simulated additively manufactured three-dimensional object.

[0196] 41. The computer-readable medium of any clause herein, comprising: generating a revised CAD file and/or a revised build file for the three-dimensional object to be additively manufactured, the revised CAD file and/or the revised build file based at least in part on the one or more material properties of the one or more test specimen and/or based at least in part on the comparing the one or more material properties of the one or more test specimen to respective ones of the one or more predictive inferences.

[0197] 42. A computer-readable medium comprising computer-executable instructions, which when executed by a processor, cause the processor to perform a method of simulating additively

manufacturing a three-dimensional object, the method comprising: generating a simulated additively manufactured three-dimensional object based at least in part on a plurality of approximate consolidation domains, the plurality of approximate consolidation domains respectively corresponding to a plurality of consolidation tracks determined from one or more digital representations of an additively manufactured three-dimensional object; and determining a predictive inference with respect to one or more material properties of a three-dimensional object to be additively manufactured based at least in part on the simulated additively manufactured three-dimensional object.
[0198] 43. The computer-readable medium of any clause herein, configured to perform the method of any clause herein.
[0199] This written description uses exemplary embodiments to describe the presently disclosed subject matter, including the best mode, and also to enable any person skilled in the art to practice such subject matter, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the presently disclosed subject matter is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

## Claims

**1**. A method comprising: actuating an image sensor to collect micrographic image data of a powder bed including melted or fused powder; determining a plurality of approximate consolidation domains based on the micrographic image data; determining a probability distribution of one or more dimensional properties of the plurality of approximate consolidation domains; generating a model of an additively manufactured three-dimensional object based at least in part on the probability distribution of the one or more dimensional properties of the plurality of approximate consolidation domains; and determining a predictive inference with respect to one or more material properties of a three-dimensional object to be additively manufactured based on the generated model.
**2**. The method of claim 1, further comprising determining the plurality of approximate consolidation domains based at least in part on a curve fitting algorithm and/or based at least in part on a data library that includes a plurality of geometric approximation candidates.
**3**. The method of claim 1, wherein the plurality of approximate consolidation domains respectively correspond to a plurality of consolidation tracks determined from the micrographic image data.
**4**. The method of claim 3, wherein the plurality of consolidation tracks correspond to a melt pool domain, a sintering domain, or a reaction domain.
**5**. The method of claim 1, wherein generating the model of the additively manufactured three-dimensional object comprises: determining a plurality of simulated consolidation layers respectively including at least some of the plurality of approximate consolidation domains.
**6**. The method of claim 1, further comprising: determining the plurality of approximate consolidation domains based at least in part on an irradiation parameter matrix, the irradiation parameter matrix comprising a plurality of nodes, respective ones of the plurality of nodes defining one or more irradiation parameter values utilized when forming a corresponding one or more consolidation tracks.
**7**. The method of claim 1, wherein at least some of the plurality of approximate consolidation domains differ from one another in respect of at least one of the one or more dimensional properties in accordance with the probability distribution.
**8**. The method of claim 1, further comprising determining a plurality of simulated consolidation artifacts in the generated model of the additively manufactured three-dimensional object based at

least in part on the one or more dimensional properties of the plurality of approximate consolidation domains.

**9**. The method of claim 8, wherein the plurality of simulated consolidation artifacts include void elements, overlap elements, or both; wherein the plurality of simulated consolidation artifacts include coarse grain structures, microcrystalline grain structures, nanocrystalline grain structures, amorphous regions, precipitates, crystalline dislocations, twinning dislocations, or combinations thereof; wherein the plurality of simulated consolidation artifacts include unmelted powder particles, unsintered powder particles, or unbound binder particles.

**10**. The method of claim 1, wherein the one or more material properties include: porosity, void sizes, void area, void aspect ratio, void maximum size, density, elastic modulus, yield strength, ductility, hardness, surface finish, mass, fatigue limit, or creep.

**11**. The method of claim 1, wherein the one or more material properties include: one or more grain structures and/or one or more crystalline structures.

**12**. The method of claim 11, wherein the one or more grain structures and/or one or more crystalline structures include at least one of: a coarse grain region, a microcrystalline grain region, a nanocrystalline grain region, an amorphous region, precipitates, crystalline dislocations, and/or twinning dislocations.

**13**. The method of claim 1, wherein the one or more dimensional properties include a geometric shape and/or one or more dimensional properties corresponding to a geometric shape.

**14**. The method of claim 1, further comprising generating a CAD file or a build file for the three-dimensional object to be additively manufactured according to the generated model, the CAD file or the build file based at least in part on the generated model or based at least in part on the predictive inference with respect to the one or more material properties of the three-dimensional object to be additively manufactured according to the generated model.

**15**. The method of claim 1, further comprising additively manufacturing the three-dimensional object based at least in part on the generated model or based at least in part on the predictive inference with respect to the one or more material properties.

**16**. The method of claim 1, further comprising collecting one or more irradiation parameters of an irradiation device that formed the melted or fused powder in the powder bed.

**17**. The method of claim 1, further comprising actuating an irradiation device to additively manufacture a three-dimensional object based at least in part on the generated model.

**18**. The method of claim 1, wherein actuating an image sensor to collect micrographic image data further comprises actuating an image sensor including a microscope.

**19**. A system comprising a processor and a memory, the memory storing instructions executable to perform the method of claim 1.

**20**. An additive manufacturing system comprising: an energy beam system including at least one irradiation device and a monitoring system; a build module including a build chamber, the build chamber including a powder bed; a powder module; and the system of claim **19**.