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Inventor(s)

EASTWOOD; Cormac et al.

SYSTEMS AND METHODS FOR COMPUTER AIDED DESIGN ANALYSIS

Abstract

Pursuant to some embodiments, systems, methods and computer program code are provided for analyzing the embodiment carbon associated with the manufacture of a part.

Inventors: EASTWOOD; Cormac (Belfast, GB), WILSON; Jonathan (Craigavon, GB), BLIGH; Amanda (Boston, MA), PETERS; Gibson (Weymouth, MA)

Applicant: APRIORI TECHNOLOGIES INC. (Concord, MA)

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Background/Summary

RELATED APPLICATIONS [0001] This application claims benefit of and priority to U.S. Provisional Patent Application Ser. No. 63/443,375 filed on Jan. 31, 2023, the contents of which are hereby incorporated by reference in their entirety for all purposes.

BACKGROUND

[0002] Manufacturers are increasingly concerned with the environmental impact of their products and processes. This is in part due to the passage of sustainability regulations in many countries which require manufacturers and brands to reduce their carbon footprints. Further, many consumers are willing to pay a premium for environmentally friendly products.

[0003] Unfortunately, it is difficult for manufacturers to evaluate a product's carbon footprint during design and planning phases. The manufacture of each part of a product impacts the environment in a number of ways. The material selected, the choice of process, and even the location of the factory are each variables that influence the amount of carbon dioxide equivalent (“CO₂e”) that is associated with the part (referred to herein as “embodied carbon”). The evaluation of each of these variables can be highly complex and are made even more complex when analyzed in conjunction with an evaluation of the cost of manufacturing a part. It would be desirable to provide systems and methods allowing manufacturers to simulate the projected cost and quantity of embodied carbon and to evaluate how changes in material selection, design, manufacturing process and manufacturing location can impact those costs and quantity of embodied carbon.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Features and advantages of the example embodiments, and the manner in which the same are accomplished, will become more readily apparent with reference to the following detailed description taken in conjunction with the accompanying drawings.

[0005] FIG. 1 is a diagram illustrating a design system pursuant to some embodiments.

[0006] FIGS. 2A-2C are diagrams illustrating processes pursuant to some embodiments.

[0007] FIGS. 3A-3I are diagrams illustrating user interfaces pursuant to some embodiments.

[0008] FIG. 4 is a diagram illustrating components of a design system pursuant to some embodiments.

[0009] Throughout the drawings and the detailed description, unless otherwise described, the same drawing reference numerals will be understood to refer to the same elements, features, and structures. The relative size and depiction of these elements may be exaggerated or adjusted for clarity, illustration, and/or convenience.

DETAILED DESCRIPTION

[0010] In the following description, specific details are set forth in order to provide a thorough understanding of the various example embodiments. It should be appreciated that various modifications to the embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the disclosure. Moreover, in the following description, numerous details are set forth for the purpose of explanation. However, one of ordinary skill in the art should understand that embodiments may be practiced without the use of these specific details. In other instances, well-known structures and processes are not shown or described in order not to obscure the description with unnecessary detail. Thus, the present disclosure is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

[0011] A designer of a part to be manufactured is often unaware of factors that can impact the

embodied carbon associated with the manufacture of the part. It is increasingly important for businesses to consider the carbon footprint of their product's manufacture. Unfortunately, comparing processes, materials and manufacturing location (all of which influence the environmental impact of manufacturing a part) is complex and difficult. For example, it is difficult to calculate embodied carbon from the material that is used to manufacture a part. To calculate the rough mass needed to manufacture a part, a user needs to understand the manufacturing process to be used as well as the stock material needed to manufacture the part. Rough mass (also referred to herein as “raw mass”) can vary by the manufacturing process used and is difficult to calculate correctly. For example, a finished machined part can be as little as 5-20% of the initial rough mass of the materials used while the finished mass of a part that is formed by casting may be around 95% of the rough mass. Further, the manufacturing process may use different steps or “routings”. As an example, a die casting manufacturing process may include routings to perform machining, milling, cutting, or drilling. Each of these routings influences the embodied carbon of the manufacture of the part. Each routing may use a different machine, and also impact the cycle time of the part manufacture. Each machine may have different energy consumption requirements. All of these variables influence the embodied carbon of a manufacturing process making it highly complex and technical to determine the embodied carbon of manufacturing a part.

[0012] Pursuant to some embodiments, systems, methods and computer program code are provided for analyzing the embodied carbon associated with the manufacture of a part. Embodiments allow the embodied carbon to efficiently be calculated for different manufacturing processes, in different geographical locations and for different materials, allowing users to analyze different scenarios and combinations of variables. Embodiments provide systems and methods for designing for sustainability which allow users to easily determine the embodied carbon of different design choices, processes, materials and manufacturing locations, thereby allowing sustainable choices to be made. Further, embodiments allow such embodied carbon analyses to be performed in conjunction with cost analyses, allowing users to compare the cost and embodied carbon of different scenarios. Embodiments provide a technical improvement to the technology of parts design and analysis, providing improved systems, methods and computer program code to analyze part designs.

[0013] Pursuant to some embodiments, a part designer or other user can interact with a system of the present invention to compare a number of different part manufacture scenarios to identify a desirable combination of cost and embodied carbon. These different scenarios are highly complex and involve the analysis of four primary variables (each of which include a number of data points and sub-variables). The four primary variables are the geometry and shape of the part, the material(s) used in the manufacture of the part, the process(es) used in the manufacture of the part and the specific location(s) of the factory(s) selected to manufacture the component. Pursuant to some embodiments, the system of the present invention may output cost and embodied carbon information to a user via a user interface which allows the user to select a combination of the four primary variables that results in a desired balance of cost and embodied carbon.

[0014] For convenience and ease of exposition, a number of terms are used herein. For example, the term “process” or “process type” is generally referred to the type of manufacturing process to be used to manufacture a part (or, using embodiments of the present invention, to analyze a part for potential manufacture using one or more process types). For example, different process types may include die casting, injection molding, machining or sheet metal bending or manipulation (although those skilled in the art will appreciate that other process types may also be used to manufacture a part and that these process types are used as examples herein). Embodiments allow users to compare the costs associated with manufacturing a part using different process types as well as to compare the embodied carbon of manufacturing the part using different process types.

[0015] As used herein, the term “cycle time” generally refers to the amount of time that one or more machines are operated in order to produce a part using a given process type. Different process

types involve different cycle time calculations. For example, a part to be made using a machining process type may have a complex cycle time that includes the sum of the cut time for each operational step in the machining process. The cycle time may also include operational time of multiple process routings using different machines. Further details of the calculation of different cycle times will be provided below.

[0016] As used herein, the term “material” when used to refer to a part to be manufactured refers to the raw material(s) used in the manufacture. For example, different types of materials include different types of plastics (e.g., for injection molding) or different types of metals (e.g., for machining, sheet metal or different types of casting).

[0017] A second, although lesser impact on embodied carbon in the manufacture of a part is the embodied carbon associated with the manufacturing process itself (the “process carbon” or “process embodied carbon”). As discussed further below, the process carbon depends in part on the factory location chosen. The factory location determines the “grid mix” associated with that factory (and the associated processes). As used herein, the term “grid mix” refers to information associated with the mix of power sources used for a factory operating in a given geographical location. For example, the “grid mix” of a factory in one location may be primarily comprised of electricity generated by coal fired plants, while the “grid mix” of a factory in another geographical location may include electricity generated by renewable energy sources. The different “grid mix” associated with the use of different factories is used by the present invention to determine the overall embodied carbon in the process.

[0018] Prior to providing a detailed description of features of the present invention, an illustrative (but not limiting) example will be described. In the illustrative example, a company wishes to manufacture a part for a piece of equipment. The part is a heat sink which will eventually be mounted on another part to dissipate heat. The company has a set of computer-aided design (CAD) drawings of the heat sink that define the dimensions and shape of the heat sink. The CAD drawings include a model stored in a file that includes a rendering/visualization of the heat sink (such as the visualization shown as part **306** of FIG. **3B**). In addition to the structural design (or geometric shape) of the heat sink, the CAD file may include additional attributes that are stored within metadata of the CAD file itself or within a parts object that is paired with the CAD file. The company now wishes to select a manufacturer to make the heat sink pursuant to the requirements specified in the CAD file.

[0019] The company knows the specifications that the heat sink needs to meet (they are defined in the CAD files), but is able to consider different manufacturing process, geographic locations of manufacturers, and materials in order to manufacture the part in a cost-effective manner while reducing the embodied carbon associated with manufacturing the part.

[0020] The company wishes to keep the cost of manufacturing down (so that the machine that incorporates the heat sink may be sold at a reasonable profit). In addition, the company wishes the manufacture of the heat sink to be sustainable—to reduce the amount of embodied carbon emissions caused by the manufacture of the heat sink. Embodiments allow the company to import or otherwise provide the design described in the CAD file to a design system for analysis. The design system of the present invention allows the company (or a user or representative of the company) to interact with the design system to analyze different scenarios to arrive at a manufacturing approach which achieves a desired balance of cost and embodied carbon. The different viable outcomes can include scenarios with different materials, different manufacturing processes, and different locations of manufacturing facilities. By interacting with the design system to adjust these different variables, the company can arrive at a manufacturing approach which achieves the desired balance of cost and embodied carbon. The selected approach can then be communicated to a manufacturer to initiate manufacture of the part. This illustrative example will be referenced below in conjunction with various figures to describe features of the present invention.

[0021] Reference is first made to FIG. 1 which is a block diagram illustrating various components of a system of the present invention. FIG. 1 depicts a system **100** which includes a design system **104** which analyzes aspects of a part to be manufactured by receiving a computer aided design (“CAD”) model. The CAD model may be provided in the form of one or more files provided by a user operating a user device **102** in communication with the design system **104** and uploaded or otherwise transmitted to a design service **106** via an interface **108**. The design service **106** may include a number of rules and computer program code configured to analyze the CAD model and perform processing as described further herein. The CAD model may also be provided in the form of one or more files retrieved via interface **108** from a design data repository **110**. For example, the design data repository **110** may be a product lifecycle management (PLM) system. For example, many part designers or other companies use PLM systems to manage CAD files. In some embodiments, the interface **108** of the design system **104** may be configured to interface or otherwise receive data from different PLM systems (e.g., to translate or convert the data from the PLM system into data that may be manipulated by the design system **104**). Although a single user device **102**, design data repository **110** and design system **104** are shown in FIG. 1, those skilled in the art will appreciate that in practical application, multiple user devices, design data repositories and/or design systems may be provided. For example, multiple user devices **102** and multiple design data repositories **110** may provide part design data to the design system **104** for analysis as described further herein.

[0022] The information from each CAD model (or data from design data repository **110**) define one or more parts to be manufactured. After ingesting this data, the design system **104** is configured to perform analyses of different aspect of a part, the part materials, manufacturing processes, and manufacturer locations to generate estimates of the embodied carbon of a number of different manufacturing options for the part as well as to generate manufacturing cost estimates for each of the different manufacturing options. The design system **104** may be operated on a local computing device or a remote, hosted device (or network of computing devices).

[0023] The design service **106**, upon receiving the design data from the interface **108**, performs operations to identify one or more geometric features of interest of the part and recommend modifications to the one or more geometric features to improve the design for manufacturability as well as cost and embodied carbon. For example, the design service **106** can make recommendations to reduce the number of tools needed, to change a specialized tooling process to a more standard process, reduce an amount of manufacturing time, reduce manufacturing cost, reduce the raw materials needed for the part, change the geographic location of where the part is manufactured to affect cost or embodied carbon due to local labor rates and electricity grid mixes, etc.

[0024] The design service **106** may present information to a user via one or more user interfaces. The user interfaces may allow the user to change one or more manufacturing variables to see their impact on cost and embodied carbon. Pursuant to some embodiments, a user may run different “scenarios” with different variables, and then compare the results of those different scenarios to arrive at a desired balance of cost and embodied carbon.

[0025] Pursuant to some embodiments, the design system **104** performs a variety of different analyses associated with the manufacture of a part using data associated with different manufacturing processes (e.g., such an analysis of die casting the part versus machining the part). In part, these analyses may use data associated with different manufacturing processes received from one or more databases such as a process database **120**. The design system **104** may also perform analyses associated with estimating cycle times for the manufacture of the part using data from one or more databases such as a factory database **130**. For example, the cycle times associated with manufacturing a part may differ based on the materials or processes used to manufacture the part and each of those different cycles may consume differing amounts of electricity. The design system **104** may also perform analyses associated with estimating the amount of embodied carbon associated with different materials that may be used for the manufacture of the part using data from

one or more databases such as material database **140**. While the term “database” is used to refer to databases **120-140**, those skilled in the art, upon reading the present disclosure, will recognize that data may be stored in or obtained from other types of information sources or data storage devices. For example, the data may be obtained from an application programming interface as a file or feed. [0026] Pursuant to some embodiments, the process database **120** may include data associated with different processes. Each manufacturing process may include, for example: numerous process feasibility checks on each process required to manufacture the part (e.g., minimum bend radius, maximum thickness, material type, achievable tolerances and consumables required by the process), modifications to cycle time based on the material type selected (e.g., adjustment factors to cutting rates based on the material cut code), and the power requirements for each stage of a process cycle time. In some embodiments, the process database **120** consists of a number of lookup tables to retrieve this information by process type.

[0027] Pursuant to some embodiments, the factory database **130** may include regionalized facility data for a large number of geographical regions. For example, the factory database **130** may include economic and machine related data associated with factories in different regions. including: data to determine facility overhead rates (e.g., electricity rate, gas rate, rent rate, insurance factors and additional support allocations), machine parameters to conduct feasibility assessments and determine machine overhead rates (e.g., machine cost, size, lifespan and maintenance factors), further machine parameters facilitate determination of the process cycle time (e.g., machine spindle power, traverse speed and tool replacement time), industrial sector labor rates by skill level and electricity embodied carbon factor for the specific facility or geographical region.

[0028] Pursuant to some embodiments, the material database **140** may contain detailed material information for hundreds of different material compositions including data for a number of different stock types, hundreds of individual stock sizes and their associated processes. This data may include: material property data to conduct feasibility assessments (e.g., material type, specific heat capacity and material hardness), material cost data for each material and for the specific stock type (when required) to manufacture the part, and material embodied carbon factors for each material.

[0029] The design system **104** may generate one or more analyses and/or recommendations allowing a user to choose a desired manufacturing approach to manufacture a part (including, for example, recommendations about which process(es) to use, what geographical locations the part should be manufactured in, and what material(s) should be used). In some embodiments, the recommendations may be generated in conjunction with other manufacturing recommendations to allow improved cost, efficiency and sustainability.

[0030] FIGS. **2A-2C** illustrate processes **200, 250, 280** that may be performed by the design system **104** (in conjunction with other components of system **100**) pursuant to some embodiments. The processes **200, 250, 280** of FIGS. **2A-2C** will be described in conjunction with various user interface figures shown in FIGS. **3A-3I**. The user interfaces of FIGS. **3A-3I** are for illustrative purposes only, and those skilled in the art, upon reading the present disclosure, will appreciate that other user interface configurations may also be used to interact with the system of the present invention. The user interfaces of FIGS. **3A-3I** may be, for example, accessed by a web browser of a user device **102** for display on a display of the user device **102** and may be configured to receive inputs from a user operating the user device **102** (e.g., via a keyboard, cursor, mouse, touch screen, or other input devices associated with the user device **102**).

[0031] The process **200** may be initiated, for example, at the request of a user operating a user device **102**. For example, the user may be a manufacturing engineer or other designer who wishes to evaluate aspects of a part to be manufactured to identify whether the part (or components thereof) may be manufactured in a more sustainable manner. Processing begins at **202** where one or more CAD files or part objects are provided to the design system. For example, a user operating user device **102** may interact with a user interface such as the user interface **302** of FIG. **3A**. The

user interface **302** (and the user interfaces shown in FIGS. 3B-3I) may, for example, be displayed on a display device **300** of a user device **102**. As shown in FIG. 3A, a user may be prompted to upload a CAD model (e.g., in one or more CAD files), select an existing (previously uploaded) CAD model, identify a location of a CAD model in a location (such as a PLM location in a design data repository **110**, etc.). In some embodiments, a user may also be able to select an existing project (e.g., involving a previously uploaded or identified CAD model that has previously been analyzed to create one or more embodied carbon and cost scenarios). As used herein, the term “scenario” will be used to refer to data associated with a part that has been analyzed by the system of the present invention using a number of input variables selected by a user). The term “project” will be used to refer to data associated with a part that has been analyzed by the system of the present invention in one or more “scenarios” (where each scenario may have different input variables selected by the user).

[0032] On receipt of the CAD files, the design system **104** may perform processing to analyze the part design. Processing continues at **204** where the design system **104** prompts the user (via a user interface displayed for the user on a display screen of the user device **102**) to provide a selection of one or more process group(s) to be used in the manufacture of the part. In general, a “process group” as used herein is a collection of manufacturing processes that share a common understanding of feature recognition and material form. For example, a user may be prompted to choose whether an analysis should be performed if the part were to be manufactured using a die casting process or a machining process. In some embodiments, the types of process groups that are available to be selected are ascertained by the design system **104** upon initial analysis of the CAD files, thereby ensuring that a user is not able to select a process group that is incompatible with the part design.

[0033] An example of a user interface that allows a user to select one or more process groups (and other input variables) is shown in FIG. 3B. As shown in FIG. 3B, a display **300** displays a number of menu options available for selection by a user, including a production scenario menu group **310**, a tolerance menu group **330**, a process & machine options menu group **340**, a cost menu group **350**, and a sustainability menu group **370**. These menu groups are provided for illustrative purposes only, and those skilled in the art, upon reading this disclosure, will appreciate that other groups or groupings may also be used. When the production scenario menu group **310** is selected (as shown in FIG. 3B), a number of input options are presented to a user (shown on the left hand side of the display **300** as items **312**, **314**, **316**, **318**, **320**) as well as a visualization area **304** displaying a rendering of the part **306**. The rendering of the part **306** is generated by the design system **104** based on the CAD files uploaded at **202**. In some embodiments, the visualization area **304** includes a number of controls that allow a user to interact with the rendering of the part **306** (e.g., to zoom, pan, rotate or otherwise inspect the part).

[0034] Processing at **204** may include the user interacting with the display **300** to select a process group at **312**. In the illustrative example, the heat sink is compatible with die casting, and die casting is presented to the user as a process group option (and has been selected by the user in FIG. 3B). Some die cast parts require machining processing as well, and this has been selected by the user in the example of FIG. 3B. In some embodiments, the display **300** of FIG. 3B is created based at least in part on an analysis of the CAD model by the design system **104** and by retrieval of process data from process database **120**. For example, this processing may include determining whether a part is compatible with a given manufacturing process and, if so, including that process as an option available for selection by the user at **312**. Pursuant to some embodiments, the compatibility of the part with a process is determined based on a feasibility evaluation by the design system **104**. In some embodiments, user permissions may also determine whether a user is able to select from among certain compatible manufacturing processes (e.g., the system may impose license restrictions based on whether the user has a license to a manufacturing process).

[0035] Once the user has selected desired process group(s) attributes, processing continues at **206**

where the design system **104** receives a selection of a raw material type (at input **318**) to be used in the manufacture of the part. In some embodiments, multiple options may be selected, and the same part may be analyzed to determine the embodied carbon of producing the same part using different types of a material. For example, if a part is to be manufactured using Nylon, embodiments allow a user to select from a list of types of Nylon (e.g., using NylonType 6 (30% glass)), and other types of Nylon compatible with the process group(s). In the illustrative example, the user selects to analyze the manufacture of the heat sink using Aluminum (more particularly, Aluminum ANSI AL380.0). In some embodiments, the input at **318** allows the user to select from a calculated list of compatible materials. The calculated list of compatible materials is determined by the design system **104** based on analysis of the CAD model as well as based on the selected process groups (e.g., based on the input received from the user at **312**). This ensures that the user is not presented with material options that are incompatible with the design or the selected process.

[0036] Once these selections have been made, processing may continue at **208** where the user provides other relevant information (e.g., such as the quantity of parts to be manufactured in the different scenarios, the size of each run or batch, etc.). This information is used by the design system **104** to compute embodied carbon as well as cost.

[0037] Once the user has selected a desired process group(s), a selection of material, information identifying desired volume and batch size, processing continues at **210** where the design system **104** prompts the user to provide a selection of a factory location in which the part (using the process group(s) selected at **204**) is to be manufactured. Pursuant to some embodiments, the selected factory location may be a “digital” or “virtual” location which will be simulated by the design system **104** using a digital twin or digital model of a factory in the corresponding geographical location. Pursuant to some embodiments, the selection of the digital factory location causes the design system **104** to use different sustainability parameters. For example, the selection of a digital factory location causes the design system **104** to retrieve factory data from a factory database **130** that include local electricity costs as well as estimates of regional CO₂ emissions (e.g., represented as kg CO₂/kWh). As an illustrative example, if the digital factory location is selected in China, the CO₂ emissions may be equal to approximately 1.02 kg CO₂/kWh, whereas a digital factory location in the United States may have CO₂ emissions equal to approximately 0.5 kg CO₂/kWh. In some embodiments, the estimates are based on the current electricity mix in the region (e.g., Coal, Natural Gas, Nuclear, Hydro or renewables). The selection of the digital factory location may have impacts on other estimates made by the design system **104** as well.

[0038] Referring again to the illustrative display **300** of FIG. 3B, the user may be presented with a drop-down menu to select a desired digital factory **314**. The options available to the user may vary based on the process group(s) selected at **312** as well as other information associated with the CAD model based on analysis by the design system **104**. For example, certain processes and designs may not be compatible with certain factory locations.

[0039] Once the user has selected a desired factory location, processing continues at **212** where the design system **104** receives information identifying one or more process routing attributes.

Different parts with different manufacturing processes may involve different process routings (essentially sub-steps of a selected manufacturing process). For example, a part (such as the heat sink in the illustrative example) may be die cast (as selected at step **204** and as selected at **312** in FIG. 3B). However, based on the design of the part, a number of process routings may be required to finish the part. These process routings may be determined by the design system **104** (based on the selected process and the CAD model) and are referred to herein as a “computed routing”. They may also include one or more preconfigured “process override(s)” which may modify one or more routings or sub-steps. In general, as used herein, a process override is a user-provided deviation from the design systems **104** default assumption. Referring again to the illustrative example, while the primary process selected for the heat sink is “Casting-Die”, the design system **104** may

determine that there are several sub-processes or routings required.

[0040] Examples of routings include a collection of processes used in a manufacturing process (for example, a routing may include one or more of stock machining, perimeter cutting, 3-Axis milling, sawing, or bulk milling processes). These routings may be needed to resize the raw material to a size appropriate for the die casting. The selection of process routings has a direct influence on both the embodied carbon of the process as well as the cost of the part. For example, if a part requires many process routing steps, it is likely that additional energy will be expended (thereby increasing the process embodied carbon). Further, if the raw material requires substantial machining or other cutting to reduce the size of the material, there may be additional waste (increasing the cost as well as the embodied carbon). Embodiments allow these variables to easily be analyzed using the system of the present invention. Pursuant to some embodiments, the options available to a user (at **316** of FIG. **3B**, for example) are determined by the design system **104** based on the CAD model and the selected process groups (at **312** of FIG. **3B**). Routing data may be retrieved by the design system **104** from process data **120**.

[0041] With these selections and additional information provided, processing continues at **214** where the design system **104** is operated to perform the analyses. In some embodiments, the analyses are performed for each combination of selections. In general, processing at **214** includes determining the material embodied carbon as well as the process embodied carbon (the sum of which is the total embodied carbon of the scenario). Pursuant to some embodiments, processing at **214** further includes determining the cost of each scenario (e.g., which is generally equal to the cost of the materials, the tooling and setup costs, the manufacturing process costs, the assembly cost as well as the labor cost for each scenario). The determination of each of these values may be an iterative process involving process data from process database **120**, factory data from factory database **130** and material data from material database **140**.

[0042] Pursuant to some embodiments, embodiments perform a determination of the rough mass required for manufacture of a part in a given scenario. This determination involves a number of factors and is influenced by the selected process group, processing routing and material. The determination of the rough mass will now be described for various process groups. If the part is selected to be manufactured using injection molding, the determination of the part's rough mass is based on a determination of the part's "finish mass" divided by the "utilization". The "utilization" is computed as: $\text{utilization} = (1 - \text{material waste factor}) * \text{mold efficiency}$, where the efficiency is based on the machine to be used (retrieved from process data **120** and factory data **130**) (and which is typically equal to 0.95). The material waste factor is expressed as a percentage and is the difference between a "runner factor" and a "regrind allowance". The regrind allowance may default to 0.25 and may also be retrieved from the factory data **130** or input as a user specified value. The runner factor is a function of the runner volume, the number of cavities of the part, and the part volume. The number of cavities of the part and the part volume are computed by the design system **104** based on the CAD model of the part. In injection molding, a "runner" is a channel cut into the mold that allows the material (such as plastic) to flow from the nozzle to the cavity (the mold). The "runner volume" is computed by the design system **104** based on the CAD model of the part as well as information about the machine to be used (retrieved from process data **120** and factory data **130**). The part "finish mass" is determined based on the "part volume" multiplied by the "material density". The part volume is determined by the design system **104** based on the CAD model of the part and the material density of the selected material (input at step **206**). The material density may be retrieved from material database **140**. In this manner, embodiments allow the efficient and accurate calculation of the rough mass of an injection molded part.

[0043] If, in a scenario, the part to be manufactured is selected to use a machining process, the selection of the proper material stock is a primary driver for calculating the rough mass (and therefore the determination of the embodied carbon of the scenario). Analysis at **214** include processing to ensure that proper material stock is selected and analyzed. This includes processing

to determine appropriate material stock alignment and cross-section. Embodiments automatically determine the most likely stock form and alignment direction. The design system **104** analyzes the geometry of the part (from the CAD model) and evaluates potential stock axis directions and cross sections from these directions. In some embodiments, a user may be able to view the selected stock axis directions and cross sections by interacting with the visualization area **304** in display **300** (e.g., as shown in FIG. **3B**). In some embodiments, a user may override the stock form and alignment recommended by the design system **104**. The design system **104** uses a number of rules to determine the stock form and alignment for a part. For example, if the part is round, a round cross-section may be assigned (allowing the selection of round stock material). If the part is generally flat and round, the part may be assigned a rectangular cross-section (and plate stock may be selected for use in the analysis). The rules applied by the design system **104** may determine that plate stock may be used based on the machines and factory selected. For example, a selected factory or machine may have a maximum value for accepting round stock and/or a maximum value for the thickness of the stock compared to the round-cross section diameter. These parameters dictate what stock material may be used at a given factory or machine (and may be retrieved, for example, from factory data **130**). The choice of appropriate input stock material for a selected factory/machine in a scenario can have a large influence on the embodied carbon of producing a part. Another factor is the stock machining material size and allowances.

[0044] In some embodiments, the design system **104** uses a concept of a machining stock allowance when determining the initial stock size required to machine a given part. A stock allowance is a small amount of extra material added to the finished part dimensions to accommodate any machining (material removal) needed to meet material quality, tolerance or finish requirements. The stock allowance may be specified in a CAD model of the part and is analyzed by the design system **104**. A non-zero stock allowance may be required to drive rough—and finish-machining of the part. A zero-value stock allowance means that the “as—supplied” stock surfaces are sufficient for the finished part, with no additional machining required to achieve desired quality, tolerances or surface finish requirements. The design system **104** determines the ideal stock size required for a part based on the dimensions of the finished part, and the amount of material required to meet any specified stock allowances (both of which are determined from the CAD model of the part). In some embodiments, when the design system **104** determines that non-hex stock is appropriate for a part, the design system **104** selects stock with the smallest standard thickness greater than or equal to the ideal thickness. This selection includes data from material data **140**.

[0045] In some embodiments, a concept of “virtual” stock may also be used in situations where actual stock is not available. The use of the concept of “virtual” stock allows analysis to be performed to see if a stock may be appropriate for the part, even if that stock is not currently available. In some embodiments, the design system **104** uses rules to apply default stock allowances. These rules may determine a minimum and a maximum stock allowance. In some embodiments a percentage stock allowance may be applied in situations where the stock material is a rectangular bar, a square bar, or plate. The percentage stock allowance may be a percentage of the part cross-sections height. In situations where the stock material is a round bar or round tube, the percentage stock allowance is a percentage of the part cross-section's outside diameter. Other rules may also be applied by the design system **104** to determine a part's stock allowance.

[0046] If, in a scenario, the part to be manufactured is selected to use sheet metal processing at **214** includes analysis specific to that material and associated manufacturing processes. For example, the material cost of a sheet metal part is based on the rough mass required to make the part. The utilization of the raw material is equal to the finish mass of the part divided by the rough mass (where “rough mass” includes any material scrap). The design system **104** uses a number of methods to determine sheet metal material utilization. These methods may be based on the process to be used to fabricate the part using sheet metal. For example, if the scenario indicates that sheet

metal is the material to be used, and the selected manufacturing process is progressive die, the design system **104** may use a true part shape nesting (TPSN) algorithm to determine material utilization. This algorithm maximizes material utilization and minimizes waste by finding the tightest nesting for parts using a blank's actual perimeter (where the blank perimeter is determined from the process data **120** and factory data **130**). In a progressive die process, the TPSN algorithm uses an optimized strip-nesting algorithm in which parts are nested in rows and all parts in a row have consistent orientations. If, in a scenario, the material is sheet metal and the process is another type of hard-tool routing (other than progressive die), the design system **104** may use a rectangular nesting by default. This approach considers length-wise and width-wise orientations of the material using the blank's smallest enclosing rectangle (determined from process data **120** and factory data **130**).

[0047] Pursuant to some embodiments, a user may be allowed to specify a desired approach for calculating utilization of a sheet metal fabricated part. For example, a user may be able to select “rectangular nesting”, “true-part nesting”, “machine default nesting” or an “override”. In some embodiments, the design system **104** may permit the user to select “rectangular nesting” if the part is rectangularly nested on a sheet, with either a length-wise or width-wise orientation. The design system **104** may permit the user to select “true-part nesting” if the selected manufacturing process is progressive die. In this nesting, the part's actual perimeter is used to determine nesting and the design system **104** will perform analyses to test various rotations of the part. The design system **104** may allow the user to select a “machine default nesting” which uses the machine's average material utilization (determined from process data **120** and factory data **130**). The design system **104** may also allow the user to “override” these nestings and instead use a fixed utilization value specified by the user.

[0048] The design system **104** performs a number of other analyses to determine the cost and embodied carbon by analyzing the part design (from the CAD model information) as well as the selected material, process, and location. For example, the design system **104** may determine if pilot hole(s) need to be drilled to fabricate a part (as well as the size of those pilot holes). Once the design system **104** performs these (and other) analyses to determine a part's rough mass, the embodied carbon for the scenario is determined by multiplying the determined rough mass by the material's carbon factor (retrieved from material data **140**). In this manner, embodiments account for all of the processes associated with creating the stock material resulting in an accurate determination of a part's embodied carbon. The rough mass is used by the design system **104** to determine a “material embodied carbon” of the part.

[0049] The design system **104** also performs a number of determinations to estimate the cycle time associated with the manufacture of a part in a given scenario. The cycle time for manufacturing a part varies by the process group selected in a scenario. For example, a part that is to be manufactured using a machining process may involve a number of cycle times that comprise the overall cycle time. A machining process may include a cut time (where the material is cut to a shape or size). The cutting part of the cycle time may have multiple steps, each of which includes an engagement time and a rapid movement time. The engagement time is the time during which a tool or part is spinning (or otherwise operating). The rapid movement time is the time during which the tool or part is being positioned (while neither the tool nor the part is spinning). Each of these involves complex calculations and data retrieved from the process data **120** and factory data **130** as well as a number of rules based on a selected process and routing. For machining processes, the engagement time is comprised of “chipmaking time” and “non-chipmaking time”. Each of these times are dependent on the specific process and machine used and may be determined by the design system **104** (with reference to data from process data **120** and factory data **130**). Once the overall cycle time has been calculated for a given scenario, embodiments utilize factory data **130** to compute an electricity carbon factor for the scenario. The electricity carbon factor may be expressed in kg CO₂/kWh and is generally dependent on the cycle time, the machine data,

and the factory location (which has an associated “grid mix”). As discussed above, the factory location may be a virtual model of a factory in a geographic location. The virtual model may include energy data defining the grid mix associated with that location. Once the manufacturing (or “process”) embodied carbon of manufacturing a part has been determined, a total embodied carbon estimate may be determined (by summing the material embodied carbon, the process embodied carbon and any logistics embodied carbon associated with the scenario). In some embodiments, the logistics embodied carbon associated with a scenario may be a user defined value. For example, a user may have an understanding of their logistics embodied carbon and may enter that value. As a default, a value of zero may be provided.

[0050] The design system **104** also operates to calculate the cost of a scenario, including a determination of the material costs, labor costs and tooling costs (with reference to costing rules and data from process data **120**, factory data **130** and material data **140**).

[0051] Processing continues at **216** where the design system **104** presents results of the analysis to the user (e.g., in the form of a user interface, spreadsheets, or the like). As an example, the user may be presented with a user interface via a display **300** as shown in FIG. 3C, where the results of an analysis for a given scenario are shown. In the display **300** of FIG. 3C, the user is presented with a spreadsheet style display of data showing the results of the analysis for one scenario. The data in FIG. 3C shows an analysis of the heat sink, where the die cast part required four processing steps in the selected routing (melting, high pressure die casting, trimming, and milling). The analyzed scenario selected a Chinese factory. The design system **104** determined that the scenario would have a total embodied carbon (measured in kg CO₂e) of 0.63, consisting of 0.52 of material embodied carbon, 0.11 of process embodied carbon and 0.00 of logistics embodied carbon to produce each heat sink. Further, the design system **104** determined that the scenario would have a fully burdened cost of \$1.77 (USD) per manufactured heat sink. In some embodiments, the user may be able to view and/or download a detailed breakdown of the cost data showing, for example, the manufacturing time(s) for each process and detailed breakdowns of the cost data. In some embodiments, the user may select the scenario presented at **216** as the final scenario for use in production. In some embodiments, the user may interact with the design system **104** to cause the specifications of the selected scenario to be transmitted to a manufacturer for use in producing the part in accordance with the scenario. In some embodiments, the specifications of the selected scenario may be transmitted to a user device **102** associated with a manufacturer.

[0052] Pursuant to some embodiments, a user may wish to compare the results of multiple scenarios to select a scenario that has a desired balance of low embodied carbon and low cost. Referring to FIG. 2B, a process **250** is shown which depicts an analysis sequence that may be used to analyze different part manufacture scenarios. The process **250** may be performed by a user operating a user device **102** to interact with the design system **104**. At **252**, the user performs an initial analysis of a part (e.g., by following the process **200** of FIG. 2A). At **254**, the user stores the initial scenario results for the part. The design system **104** stores the scenario results for later retrieval and analysis. The user may then provide information at **256** to modify one or more variables in the scenario to create a new scenario. For example, the user may choose a different process group, a different factory location, a different process routing, a different material, or a different production volume or batch size. Processing continues at **258** where the design system **104** stores the updated scenario results for later retrieval and analysis. Processing at **256** and **258** may be repeated as desired by the user to provide different combinations of variables for analysis.

[0053] Processing continues at **260** where design system **104** displays a comparison of the various scenarios for the manufacture of the part to the user. As discussed above, each scenario may be saved by a user, and each scenario may involve a selection of one or more different input variables (e.g., the user can modify the process group, factory location, material selection, etc.).

Embodiments allow the results of each of these different scenarios to be viewed by a user. For example, referring to FIG. 3H, processing at **260** may involve the design system **104** presenting a

display **300** to a user in chart form, showing the results of each scenario. The display **300** may include an area **390** which lists the different scenarios run for a selected part as well as an area **392** which displays results for each scenario. In the display **300** of FIG. 3H, the user may click on, hover over using a cursor, or otherwise select a specific scenario in the list of scenarios **390** to view further details about that scenario (for example, hovering over a scenario may cause a modal or window to overlay a portion of the display **300** showing the variables selected in each scenario). In the area **392**, the user may select output data to graph for each scenario. For example, the user may select to display the fully burdened cost data and total embodied carbon for each scenario. Different cost options may also include material cost, labor cost, fixture cost, etc. Different embodied carbon options may include total embodied carbon, material embodied carbon, process embodied carbon, logistics embodied carbon, etc. In the illustrative example, the user may determine that scenario **3** achieves the user's desired balance of low cost and relatively low embodied carbon. By presenting the user with such a display comparing scenarios, embodiments allow users to efficiently compare highly complex scenarios. The user may interact with the results to determine which scenario produces the desired results (e.g., by balancing the embodied carbon of each scenario with the cost of each scenario, the user is better able to select a scenario that matches a desired outcome). In some embodiments, the user may interact with the design system **104** to select one of the scenarios as the final scenario for use in manufacturing a part. In some embodiments, the design system **104** may transmit the scenario to a manufacturer to control the manufacture of the part in accordance with the selected scenario.

[0054] Pursuant to some embodiments, the design system **104** may be configured to automatically analyze data input by a user to ensure that the user has selected, or is only permitted to select, a valid combination of materials, processes and factory locations. Further, the design system **104** may be configured to automatically suggest alternative materials, processes or factory locations that may result in either reduced cost or reduced embodied carbon. For example, referring to FIG. 2C, in some embodiments, a process **280** may be performed after a user has run a scenario involving a particular selection of material. The design system **104** performs processing to analyze the material selection (and other selected attributes) at **282**. At **284**, the design system **104** determines whether or not one or more alternative materials are available (e.g., materials that are compatible with the part design). At **286**, the design system **104** causes a user interface to be presented to the user listing the alternative(s). For example, referring again to FIG. 3E, the user interface presenting the alternative(s) may be navigated to by the user from item **375** (the user interface area that shows the material carbon effect relative to one or more alternatives). If the user wishes to analyze the alternative(s) in more detail, the user may click on the area (or on a button) associated with item **375** and may be presented with a user interface **300** shown in FIG. 3I. As shown in FIG. 3I, the user interface lists one or more alternative materials that have different carbon emissions and cost in an area **380**. The user may be shown the material that was analyzed in the current scenario and a list of potential alternative materials. The user may select to analyze one or more of the alternative materials which will cause the design system **104** to perform an analysis using the previously entered criteria as well as the newly selected material.

[0055] Referring again to FIG. 2C, if the user selects one or more alternatives at **288**, processing continues at **290** where the alternative scenario(s) are run using the selected alternative material(s). In this manner, embodiments allow a user to easily generate and compare multiple scenarios using materials (or other inputs) that may result in different cost or carbon effects. While example user interfaces were shown in which alternative materials were automatically identified by the design system **104**, the system may also automatically identify other alternatives (such as factory location, process groups, etc.). In this manner, embodiments allow highly complex comparisons of scenarios involving highly complex analyses with multiple variables to easily be reviewed by a user so that a selection of a scenario can be made that achieves a desired balance of carbon effect and cost.

[0056] Pursuant to some embodiments, a user may be provided with a number of options and

interfaces while creating or evaluating a scenario. For example, referring again to FIG. 3B, the user may be presented with an option **309** to save the current scenario. Further, the user may be presented with an option **308** to view part details. An illustrative user interface that may be displayed to a user who selects to view part details is shown in FIG. 3G. In the display **300** of FIG. 3G, a user is presented with a tabular view of the process routings associated with the selected process group for the part. Continuing the illustrative example, the process routings shown are for the die casting process for the heat sink in the Chinese digital factory. As shown, the die casting routing for this part in this scenario includes four processes: melting, high pressure die casting, trimming, and 3 Axis Milling. The display **300** of FIG. 3G shows embodied carbon information associated with each of these process steps.

[0057] A user may also be able to view cost information for the current scenario. For example, referring to FIG. 3C, a display **300** is shown which may be displayed to a user who has selected the cost menu item **350**. The user may also be able to view sustainability information for the current scenario. For example, referring to FIG. 3D, a display **300** is shown which may be displayed to a user who has selected the sustainability menu item **370**. In some embodiments, the sustainability menu item **370** may be presented as a single display or may be broken into multiple displays (as shown in FIGS. 3D-3F). In the display **300** of FIG. 3D, the user is shown a sustainability screen displaying a embodied carbon summary **372** of the current scenario (with information noting how many of the evaluated processes are missing sustainability information, as well as information indicating the computed embodied carbon). A user may select to compare **309** the current scenario with other scenarios.

[0058] Referring to FIG. 3E, a user who has selected to view the material embodied carbon information may be presented with a display **300** that shows the material embodied carbon of the current scenario. Referring to FIG. 3F, a user who has selected to view the manufacturing embodied carbon information may be presented with a display **300** that shows the manufacturing embodied carbon of the current scenario. As shown, a table may also be presented showing the manufacturing embodied carbon of each process in the routing. In the illustrative example, the melting process and the trim process account for the majority of the manufacturing process embodied carbon. Those skilled in the art, upon reading this disclosure, will appreciate that other displays, interfaces and analyses may be provided to users.

[0059] FIG. 4 illustrates a computing system **400** that can be configured to function as the design system **104** of FIG. 1, in accordance with an example embodiment. For example, the computing system **400** may be a database node, a server, a cloud platform, a user device, or the like. In some embodiments, the computing system **400** may be distributed across multiple devices. Referring to FIG. 4, the computing system **400** includes a network interface **410**, a processor **420**, an output **430**, and a storage device **440** such as an in-memory. Although not shown in FIG. 4, the computing system **400** may also include or be electronically connected to other components such as a display, an input unit, a receiver, a transmitter, a persistent disk, and the like. The processor **420** may control the other components of the computing system **400**.

[0060] The network interface **410** may transmit and receive data over a network such as the Internet, a private network, a public network, an enterprise network, and the like. The network interface **410** may be a wireless interface, a wired interface, or a combination thereof. The processor **420** may include one or more processing devices each including one or more processing cores. In some examples, the processor **420** is a multicore processor or a plurality of multicore processors. Also, the processor **420** may be fixed or it may be reconfigurable.

[0061] The output **430** may output data to an embedded display of the computing system **400**, an externally connected display, a display connected to a cloud platform, another computing device (such as, for example, a display used in conjunction with a user device **102** and/or a display used in conjunction with a design data source **110**), and the like. For example, the output **430** may include a port, an interface, a cable, a wire, a board, and/or the like, with input/output capabilities. The

network interface **410**, the output **430**, or a combination thereof, may interact with applications executing on other devices. The storage device **440** is not limited to a particular storage device and may include any known memory device such as RAM, ROM, hard disk, and the like, and may or may not be included within the cloud environment. The storage **440** may store software modules or other instructions which can be executed by the processor **420** to perform the methods **200**, **250**, **280** shown in FIG. 2.

[0062] According to various embodiments, the processor **420** may receive an image including a geometric design of a part. The image may include a technical model such as CAD, or the like. The processor **420** may be configured to analyze the technical model to perform processing as described herein. Furthermore, the output **430** may output, to a user interface, information about the embodied carbon of different approaches to manufacture the part.

[0063] As will be appreciated based on the foregoing specification, the above-described examples of the disclosure may be implemented using computer programming or engineering techniques including computer software, firmware, hardware or any combination or subset thereof. Any such resulting program, having computer-readable code, may be embodied or provided within one or more non transitory computer-readable media, thereby making a computer program product, i.e., an article of manufacture, according to the discussed examples of the disclosure. For example, the non-transitory computer-readable media may be, but is not limited to, a fixed drive, diskette, optical disk, magnetic tape, flash memory, external drive, semiconductor memory such as read-only memory (ROM), random-access memory (RAM), and/or any other non-transitory transmitting and/or receiving medium such as the Internet, cloud storage, the Internet of Things (IoT), or other communication network or link. The article of manufacture containing the computer code may be made and/or used by executing the code directly from one medium, by copying the code from one medium to another medium, or by transmitting the code over a network.

[0064] The computer programs (also referred to as programs, software, software applications, “apps”, or code) may include machine instructions for a programmable processor, and may be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the terms “machine-readable medium” and “computer-readable medium” refer to any computer program product, apparatus, cloud storage, internet of things, and/or device (e.g., magnetic discs, optical disks, memory, programmable logic devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The “machine-readable medium” and “computer-readable medium,” however, do not include transitory signals. The term “machine-readable signal” refers to any signal that may be used to provide machine instructions and/or any other kind of data to a programmable processor.

[0065] The above descriptions and illustrations of processes herein should not be considered to imply a fixed order for performing the process steps. Rather, the process steps may be performed in any order that is practicable, including simultaneous performance of at least some steps. Although the disclosure has been described in connection with specific examples, it should be understood that various changes, substitutions, and alterations apparent to those skilled in the art can be made to the disclosed embodiments without departing from the spirit and scope of the disclosure as set forth in the appended claims.

Claims

1-19. (canceled)

20. A computing system comprising: a communication port coupled to the computing system to facilitate a transmission of data with a remote user device via an API (application programming interface); and a processor configured to: receive, from a user device via the API, one or more computer aided design (CAD) files including information representing a CAD model, a structural

design, and a specification of attributes of at least a first part, and a request to perform an analysis of at least the first part described by the CAD model; determine, automatically based on information in the one or more CAD files, at least one process group compatible with the structural design of the at least the first part; receive information identifying a manufacturing scenario, the manufacturing scenario including a user selected indication of one or more of the determined at least one process group and a material, each process group in the selected one or more of the determined at least one process group including one or more manufacturing processes to manufacture at least the first part; determine, based on the information identifying the manufacturing scenario, an embodied carbon of the manufacturing scenario; present, to a user, information associated with the information identifying the manufacturing scenario including the identified manufacturing scenario and the embodied carbon determined for the identified manufacturing scenario; transmit, via a network interface in response to a user selected indication of the identified manufacturing scenario, specifications of the identified manufacturing scenario to a user device associated with a manufacturer to produce at least the first part in accordance with the identified manufacturing scenario, including the material embodied carbon.

21. The computing system of claim 20, wherein the processor is further configured to store the information associated with the embodied carbon of the manufacturing scenario.

22. The computing system of claim 21, wherein the processor is further configured to: receive information identifying a second manufacturing scenario associated with at least the first part, the second manufacturing scenario including information updating a value of at least one of (i) the selected process group and (ii) the selected material; determine, based on the information identifying the second manufacturing scenario, a second embodied carbon of the manufacturing scenario; and present information associated with the second embodied carbon of the second manufacturing scenario to a user.

23. The computing system of claim 22, wherein the processor is further configured to store the information associated with the second embodied carbon of the second manufacturing scenario.

24. The computing system of claim 20, wherein the processor is further configured to determine, based on the information identifying the manufacturing scenario, an estimated cost to produce the at least first part using the manufacturing scenario.

25. The computing system of claim 23, wherein the processor is further configured to generate, for display to a user device, an interface comparing the embodied carbon of the manufacturing scenario and the second manufacturing scenario.

26. The computing system of claim 20, wherein the processor is further configured to: automatically determine, based on the information identifying the manufacturing scenario, at least a first alternative material compatible with at least the first part; and generate, for display to a user device, an interface presenting information associated with the at least first alternative material.

27. The computing system of claim 26, wherein the processor is further configured to receive, from the user, a selection of the at least first alternative material and a request to create a further manufacturing scenario, the further manufacturing scenario including the selected process group and the at least first alternative material.

28. The computing system of claim 27, wherein the processor is further configured to generate, for display to a user operating a user device, an interface comparing the embodied carbon of the manufacturing scenario and the further manufacturing scenario.

29. A method for operating a design system, comprising: receiving, from a user device via an API (application programming interface), one or more computer aided design (CAD) files including information representing a CAD model, a structural design, and a specification of attributes of at least a first part; receiving, via the API, a request to perform an analysis of at least the first part described by the CAD model; determining, based on information in the one or more CAD files, at least one process group compatible with the structural design of the at least the first part; receiving an indication of a user selection of one or more of the determined at least one process group;

receiving information identifying a manufacturing scenario, the manufacturing scenario including a user selected one or more of the determined at least one process group and a selected material, each process group in the selected one or more of the determined at least one process group including one or more manufacturing processes to manufacture at least the first part; determining, automatically based on the information identifying the manufacturing scenario, an embodied carbon of the manufacturing scenario; presenting, to a user, information associated with the information identifying the manufacturing scenario including the identified manufacturing scenario and the embodied carbon determined for the identified manufacturing scenario; transmitting, via network interface in response to a user selected indication of the identified manufacturing scenario, specifications of the identified manufacturing scenario of the presented information to a user device associated with a manufacturer to produce at least the first part in accordance with the identified manufacturing scenario, including the embodied carbon.

30. The method of claim **10**, further comprising storing the information associated with the embodied carbon of the manufacturing scenario.

31. The method of claim **30**, further comprising: receiving information identifying a second manufacturing scenario associated with at least the first part, the second manufacturing scenario including information updating a value of at least one of (i) the selected process group and (ii) the selected material; determining, based on the information identifying the second manufacturing scenario, a second embodied carbon of the manufacturing scenario; and causing information associated with the second embodied carbon of the second manufacturing scenario to be displayed to a user.

32. The method of claim **31**, further comprising storing the information associated with the second embodied carbon of the second manufacturing scenario.

33. The method of claim **29**, further comprising determining, based on the information identifying the manufacturing scenario, an estimated cost to produce the part using the scenario.

34. The method of claim **32**, further comprising generating, for display to the user, an interface comparing the embodied carbon of the manufacturing scenario and the embodied carbon of the second manufacturing scenario.

35. The method of claim **29**, further comprising: automatically determining, based on the information identifying the manufacturing scenario, at least a first alternative material compatible with at least the first part; and generating, for display to a user device, an interface presenting information associated with the at least first alternative material.

36. The method of claim **35**, further comprising receiving, from the user, a selection of the at least first alternative material and a request to create a further manufacturing scenario, the further manufacturing scenario including the selected process group and the at least first alternative material.

37. The method of claim **36**, further comprising generating, for display to a user device, an interface comparing the embodied carbon of the manufacturing scenario and the further manufacturing scenario.
