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Filtering materials based on user intent capture using large language models

Abstract

Various embodiments are directed towards techniques for determining materials for computer-generated designs that include generating a query prompt based on an assembly context, transmitting the query prompt to a plurality of large language model (LLM) agents for processing, receiving a plurality of material attribute filters from the plurality of LLM agents, where each LLM generates a different material attribute filter when processing the query prompt, combining the material attribute filters included in the plurality of material attribute filters to produce a material query, querying a material database using the material query to identify at least one potential material to use for a design, evaluating simulation results to determine whether the at least one material is an appropriate material to use for the design.

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Background/Summary

BACKGROUND

Field of the Various Embodiments

(1) The various embodiments relate generally to computer-aided design, material science, and artificial intelligence and, more specifically, to filtering materials based on user intent capture using large language models.

Description of the Related Art

(2) Engineers and designers oftentimes use computer-aided design (CAD) software to create digital designs of products and systems. Among other things, CAD software enables engineers and designers to visualize and simulate their designs, enabling quick and efficient iteration. CAD software allows for the creation of complex three-dimension (3D) models, accurate dimensioning, and the simulation of real-world conditions, such as stress analysis and motion and dynamic simulation. CAD software also facilitates collaboration among team members and stakeholders, as digital designs can be easily shared and reviewed. As a general matter, CAD software plays an important role in the engineering and design process by streamlining design workflows and enabling the development of high-quality, innovative designs.

(3) One aspect of the engineering and design workflow is the selection of one or more appropriate materials to use for the product being designed. The material from which a product is made can have a substantial impact on several aspects the product including, without limitation, the functionality of the product, the strength of the product, the weight of the product, and the durability of the product. Additionally, the materials used for a product can impact the aesthetic aspects of the product, such as the smell and feel of the product. For these reasons, engineers and

designers usually consider many different material options for their designs. In selecting the appropriate materials, an engineer or designer may assess the expected usage requirements of a design, consult with a materials experts about the characteristics and limitations of various materials, and/or run simulations of the design using different materials.

(4) One drawback of the above process for selecting materials for a design is the level of technical expertise and know-how needed to select the appropriate materials for a given design. Many engineers and designers do not have the necessary technical knowledge to evaluate complex material selection problems without consulting a materials expert. In this regard, an engineer or designer typically has to consider the different physical and aesthetic properties of numerous materials in the context of how a given design is expected to be used. For example, an engineer designing a bicycle may need to consider materials that are sturdy enough to provide stability, light enough to lift easily, and weather resistant if left outside. If an engineer or designer does not have the requisite materials expertise or fails to consider certain material or use cases for a design, unintended mistakes or non-optimized designs can result, which sometimes are discoverable, if at all, only after one or more design prototypes have been manufactured. These problems are exacerbated when a design includes multiple different materials because the interactions among the materials have to be considered, which adds another level of complexity to the materials selection process and increases the need for materials expertise.

(5) Additionally, material selection plays an important role when determining the manufacturing process that should be used to manufacture a given design. Different manufacturers typically specialize in different specific subsets of materials and manufacturing processes, and different manufacturing processes have different costs. Without the requisite materials expertise, an engineer or designer may not be able to assess different manufacturing processes effectively and, as a result, make costly planning mistakes by selecting an incorrect or suboptimal material for a design.

(6) Another drawback of conventional approaches for determining what materials should be used for a design is that the process typically involves selecting one or more materials for the design, incorporating those material into the design, and then performing simulations to test the efficacy of the selected materials. Material libraries in convention CAD applications can include hundreds or thousands of different materials. Having to iterate through these steps for numerous different materials consumes a lot of time and can impinge on the design timeline. Consequently, an engineer or designer usually can test only a subset of the materials that are available to use for a given design. As a result, only a portion of the overall design space is normally explored, leading to sub-optimal material choices and reduced design quality.

(7) As the foregoing illustrates, what is needed in the art are more effective techniques for determining the materials to use with CAD object designs.

SUMMARY

(8) One embodiment of computer-implemented method for determining materials for computer-generated designs includes generating a query prompt based on an assembly context, transmitting the query prompt to a plurality of large language model (LLM) agents for processing, receiving a plurality of material attribute filters from the plurality of LLM agents, where each LLM generates a different material attribute filter when processing the query prompt, combining the material attribute filters included in the plurality of material attribute filters to produce a material query, querying a material database using the material query to identify at least one potential material to use for a design, and evaluating simulation results to determine whether the at least one material is an appropriate material to use for the design. Further, the simulation results are generated from at least one simulation of the design using the at least one material.

(9) One technical advantage of the disclosed techniques relative to the prior art is that the disclosed techniques enable suitable materials for designs to be automatically identified and evaluated without requiring users and designers to have the have the level of knowledge about material science, mechanics, mechanical engineering, or mechanical design that is typically required with

conventional approaches. Accordingly, computer-aided design applications that incorporate the disclosed techniques can be accessed by a far broader range of users and designers to generate designs made of suitable materials than what conventional computer-aided design applications allow. Further, because the disclosed techniques can substantially reduce the amount of time required to identify suitable materials for designs, the disclosed techniques enable users and designers to more fully explore the overall design space, which can result in more optimized materials being selected for and incorporated into designs, thereby increasing overall design quality. These technical advantages provide one or more technological advances over prior art approaches.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) So that the manner in which the above recited features of the various embodiments can be understood in detail, a more particular description of the inventive concepts, briefly summarized above, may be had by reference to various embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of the inventive concepts and are therefore not to be considered limiting of scope in any way, and that there are other equally effective embodiments.
- (2) FIG. 1 is a conceptual block diagram of a computing device that is configured to implement one or more aspects of the various embodiments;
- (3) FIG. 2 is a more detailed illustration of the material selection module of FIG. 1, according to various embodiments;
- (4) FIG. 3 is a more detailed illustration of the LLM chain-of-thought engine of FIG. 2, according to various embodiments; and
- (5) FIG. 4 sets forth a flow diagram of method steps for determining appropriate materials for a design, according to various embodiments.

DETAILED DESCRIPTION

- (6) In the following description, numerous specific details are set forth to provide a more thorough understanding of the various embodiments. However, it will be apparent to one of skilled in the art that the inventive concepts may be practiced without one or more of these specific details.
- (7) System Overview
- (8) FIG. 1 is a conceptual block diagram of a computing device **100** that is configured to implement one or more aspects of the various embodiments. Computer device **100** may include any type of computing system, including, without limitation, a server machine, a server platform, a desktop machine, a laptop machine, a hand-held/mobile device, a digital kiosk, an in-vehicle infotainment system, and/or a wearable device. In some embodiments, computing device **100** is a server machine operating in a data center or a cloud computing environment that provides scalable computing resources as a service over a network.
- (9) In various embodiments, computing device **100** includes, without limitation, the processor(s) **142** and the memory(ies) **144** coupled to a parallel processing subsystem **122** via a memory bridge **105** and a communication path **123**. Memory bridge **105** is further coupled to an I/O (input/output) bridge **107** via a communication path **106**, and I/O bridge **217** is, in turn, coupled to a switch **116**.
- (10) In one embodiment, I/O bridge **107** is configured to receive user input information from optional input devices **108**, such as a keyboard, mouse, touch screen, sensor data analysis (e.g., evaluating gestures, speech, or other information about one or more uses in a field of view or sensory field of one or more sensors), and/or the like, and forward the input information to the processor(s) **142** for processing. In some embodiments, computing device **100** may be a server machine in a cloud computing environment. In such embodiments, computing device **100** may not

include input devices **108** but may receive equivalent input information by receiving commands (e.g., responsive to one or more inputs from a remote computing device) in the form of messages transmitted over a network and received via the network adapter **118**. In some embodiments, switch **116** is configured to provide connections between I/O bridge **107** and other components of the computing device **100**, such as a network adapter **118** and various add-in cards **120** and **121**.

(11) In some embodiments, I/O bridge **107** is coupled to a system disk **114** that may be configured to store content and applications and data for use by processor(s) **142** and parallel processing subsystem **122**. In one embodiment, system disk **114** provides non-volatile storage for applications and data and may include fixed or removable hard disk drives, flash memory devices, and CD-ROM (compact disc read-only-memory), DVD-ROM (digital versatile disc-rom), Blu-ray, HD-DVD (high-definition DVD), or other magnetic, optical, or solid state storage devices. In various embodiments, other components, such as universal serial bus or other port connections, compact disc drives, digital versatile disc drives, film recording devices, and the like, may be connected to I/O bridge **107** as well.

(12) In various embodiments, memory bridge **105** may be a northbridge chip, and I/O bridge **107** may be a southbridge chip. In addition, communication paths **106** and **123**, as well as other communication paths within computing device **100**, may be implemented using any technically suitable protocols, including, without limitation, AGP (accelerated graphics port), hyper-transport, or any other bus or point-to-point communication protocol known in the art.

(13) In some embodiments, parallel processing subsystem **122** comprises a graphics subsystem that delivers pixels to an optional display device **110** that may be any conventional cathode ray tube, liquid crystal display, light-emitting diode display, and/or the like. In such embodiments, the parallel processing subsystem **122** may incorporate circuitry optimized for graphics and video processing, including, for example, video output circuitry. Such circuitry may be incorporated across one or more parallel processing units (PPUs), also referred to herein as parallel processors, included within the parallel processing subsystem **122**.

(14) In some embodiments, the parallel processing subsystem **122** incorporates circuitry optimized (e.g., That undergoes optimization) for general purpose and/or compute processing. Again, such circuitry may be incorporated across one or more PPUs included within parallel processing subsystem **122** that are configured to perform such general purpose and/or compute operations. In yet other embodiments, the one or more PPUs included within parallel processing subsystem **122** may be configured to perform graphics processing, general purpose processing, and/or compute processing operations. System memory **144** includes at least one device driver configured to manage the processing operations of the one or more PPUs within parallel processing subsystem **122**. In addition, the system memory **144** includes the CAD application **110**. Although described herein primarily with respect to the CAD application **110**, techniques disclosed herein can also be implemented, either entirely or in part, in other software and/or hardware, such as in the parallel processing subsystem **122**.

(15) In various embodiments, parallel processing subsystem **122** may be integrated with one or more of the other elements of FIG. **1** to form a single system. For example, parallel processing subsystem **122** may be integrated with processor **142** and other connection circuitry on a single chip to form a system on a chip (soc).

(16) In some embodiments, processor(s) **142** includes the primary processor of computing device **100**, controlling and coordinating operations of other system components. In some embodiments, the processor(s) **142** issues commands that control the operation of PPUs. In some embodiments, communication path **123** is a PCI express link, in which dedicated lanes are allocated to each PPU. Other communication paths may also be used. The PPU advantageously implements a highly parallel processing architecture, and the PPU may be provided with any amount of local parallel processing memory (pp memory).

(17) It will be appreciated that the system shown herein is illustrative and that variations and

modifications are possible. The connection topology, including the number and arrangement of bridges or the number of parallel processing subsystems **212**, may be modified as desired. For example, in some embodiments, system memory **144** could be connected to the processor(s) **142** directly rather than through memory bridge **105**, and other devices may communicate with system memory **144** via memory bridge **105** and processor **142**. In other embodiments, parallel processing subsystem **122** may be connected to I/O bridge **107** or directly to processor **142**, rather than to memory bridge **105**. In still other embodiments, I/O bridge **107** and memory bridge **105** may be integrated into a single chip instead of existing as one or more discrete devices. In certain embodiments, one or more components shown in FIG. **1** may not be present. For example, switch **116** could be eliminated, and network adapter **118** and add-in cards **120**, **121** would connect directly to I/O bridge **107**. Lastly, in certain embodiments, one or more components shown in FIG. **1** may be implemented as virtualized resources in a virtual computing environment, such as a cloud computing environment. In particular, the parallel processing subsystem **122** may be implemented as a virtualized parallel processing subsystem in at least one embodiment. For example, the parallel processing subsystem **122** may be implemented as a virtual graphics processing unit(s) (VPU(s)) that renders graphics on a virtual machine(s) (VM(s)) executing on a server machine(s) whose GPU(s) and other physical resources are shared across one or more VMs.

(18) In some embodiments, the CAD application **110** is configured to produce designs, select appropriate materials, and perform physical simulations of user designs with potential materials. CAD application **110** includes material selection module **112** and simulation module **114**. Material selection module **112** is used in the selection of appropriate materials. Techniques that material selection module **112** can use to select appropriate materials are discussed in greater detail below in conjunction with FIGS. **2** and **3**. Simulation module **114** is used in the simulation of user designs with potential materials.

(19) Filtering Materials Based on User Intent Capture

(20) FIG. **2** is a more detailed illustration of material selection module **112** of FIG. **1**, according to various embodiments. As shown, material selection module **112** includes LLM chain-of-thought engine **204**, material library **208**, and reflection module **218**. Material selection module **112** also interfaces with simulation module **114** to receive results from simulations that are performed on a given design using potential materials **210**, as described in greater detail below. In operation, material selection module **112** accepts assembly context **202** as input and performs a series of operations to generate appropriate materials **214**.

(21) Assembly context **202** includes structured information and context about a design being developed in CAD application **110**. In various embodiments, assembly context **202** includes information directly from the CAD environment (e.g., the design name, design volume, surface area) as well as a user-provided description of the intent or purpose of the design. For example, the user may specify that the design being developed is a bicycle that is robust enough to handle various riding conditions and can handle exposure to various kinds of weather. Assembly context **202** also includes user-specified design criteria that specify the acceptable operating ranges of the design. For example, if the user is designing a lightweight bicycle for racing, the design criteria may specify a maximum weight for the bicycle.

(22) LLM chain-of-thought engine **204** accepts assembly context **202** as input and generates a material query **206**. As described in greater detail below in conjunction with FIG. **3**, to generate material query **206**, LLM chain-of-thought engine **204** initializes a set of LLM agents, where each LLM agent is initialized with context associated with both a description and the properties of a given material attribute (e., density, elastic limit, Young's modulus). The material attribute context provides the LLM agent with information about the distribution of values for the material attribute and how different attribute values manifest in different physical and aesthetic properties when implemented in a design. LLM chain-of-thought engine **204** processes assembly context **202** into a query prompt passed to each given LLM agent related to how, if at all, assembly context **202** places

restrictions on the material attribute corresponding to the given LLM agent. LLM chain-of-thought engine **204** then prompts each given LLM agent to identify an appropriate filter for the attribute corresponding to the given LLM agent. The different identified filters are subsequently combined to produce material query **206**.

(23) Material library **208** includes a structured list of materials available for the design being developed and various material properties. In various embodiments, material library **208** may be a module of CAD application **110** or an external third-party software application. Material library **208** applies material query **206** to the structured list of materials and, based on the different filters included in material query **206**, filters the available materials in material library **208** to produce potential materials **210**. Potential materials **210** is the set of available materials that satisfy all the filtering criteria specified in material query **206**.

(24) Potential materials **210** are passed to simulation module **114** along with assembly context **202**. In various embodiments, simulation module **114** is a submodule of CAD application **110** that is capable simulating various physical and chemical phenomena for a given design, where the design is made of a specified material. Simulation module **114** performs simulations of the design being developed based on potential materials **210**, where, for a given simulation, a different potential material **210** is used for the design being developed. Simulation module **114** generates simulation results for each simulation performed. For example, simulation module **114** may compute for the design being developed with a potential material **210** an estimated weight of the resulting design, or the design's robustness to various forces and strains. After simulations have been completed for all potential materials **210**, the simulation results are passed to logic **216** for assessment.

(25) At logic **216**, the simulation results are compared to the design criteria included in assembly context **202** to determine which, if any, of potential materials **210** meet the design criteria. Any potential material **210** that meets the design criteria is returned as an appropriate material **214**. If none of potential materials **210** meets the design criteria, then the simulation results are passed to reflection module **218**. In some embodiments, rather than passing the simulation results to reflection module **218**, logic **216** may, instead, output a message informing the user that no appropriate materials could be identified. In such cases, the user can update the information included in assembly context **202**, and the updated assembly context **202** can be inputted into LLM chain-of-thought engine **204**, as described above.

(26) Reflection module **218** processes the simulation results and constructs a query prompt to prompt the LLM agents to create new filters to respond to the simulation results. Each LLM agent uses the chain-of-thought procedure to retain memory of prompts and context from previous iterations. The query prompt constructed by reflection module **218** takes advantage of the chain-of-thought procedure to leverage prior information. Therefore, each LLM agent can be updated with the current simulation results to produce updated filters. The query prompt constructed by reflection module **218** is passed to LLM chain-of-thought engine **204**, and the process implemented by material selection module **112** and simulation module **114** repeats until a set of appropriate materials **214** is identified.

(27) FIG. 3 is a more detailed illustration of LLM chain-of-thought engine **204** of FIG. 2, according to various embodiments. As shown, LLM chain-of-thought engine **204** includes query prompt generator **308**, query aggregator **310**, and material attribute details **302(1) . . . (N)**. As also shown, LLM chain-of-thought engine **204** additionally interfaces with LLM module **304**, which includes LLM agents **306(1) . . . (N)**. Reflection module **218** also interfaces with LLM module **304**. In operation, LLM chain-of-thought engine **204** accepts assembly context **202** as input and produces material query **206** as an output during a first iteration. If no appropriate materials **214** are produced in the first iteration through LLM chain-of-thought engine **204**, then reflection module **218** passes the simulation results generated by simulation module **114** (as described above in conjunction with FIG. 2) to LLM module **304**, which in combination with query aggregator **310** generates an updated material query **206** as an output. The updated material query **206** is processed

within material selection module **112** similarly to how the initial material query **206** is processed within material selection module **112** (as also described above in conjunction with FIG. 2). Notably, any time an iteration through LLM chain-of-thought module **204** does not result in one or more appropriate materials being identified, reflection module **218** passes the simulation results generated by simulation module **114** to LLM module **304** so that an updated material query **206** can be generated and processed.

(28) Turning now to the more specific operations of LLM chain-of-thought engine **204** and LLM module **304**, assembly context **202** is first passed to query prompt generator **308**, which processes the structured design information of assembly context **202** into a natural language query prompt appropriate for an LLM. The query prompt describes the design being developed and the user-specified intent or purpose for the design and prompts the LLM agent **306** to suggest the range of material attribute values for a given material attribute that likely would meet the design criteria specified by the user. The query prompt further requests LLM agent **306** to return the range of material attribute values as a material attribute filter in a structured format. For example, the query prompt may ask the LLM agent **306** whether assembly context **202** includes any information about a specific material attribute. If so, the query prompt further requests the agent to extract the relevant information from assembly context **202** as a range on the values relevant material attribute, and to return the range as a material attribute filter in a structured format (e.g., JSON, SQL).

(29) Material attribute details **302** are a collection of material attributes, detailed natural language descriptions of what the material attributes represent, and the physical, chemical, and aesthetic properties that manifest for different material attribute values. In some embodiments, each material attribute details **302** provides context about a particular material attribute to a different corresponding LLM agent **306** as well as reference information about the range and distribution of values for that particular material attribute. In some embodiments, material attributes **302** may not reside within LLM chain-of-thought engine **204** and, instead, be included in or associated with material library **208** or some other external source of material information.

(30) LLM Module **304** hosts and manages one or more LLM agents **306**. As shown, LLM module **304** executes outside of CAD application **110**, either as a separate application in the computing device **100** or as an application executing on another computing device that interacts with computing device **100**. In other embodiments LLM module **304** can be incorporated into LLM chain-of-thought engine **204** or otherwise included in CAD application **110**.

(31) In operation, material attribute details **302** are used to initialize corresponding LLM agents **306** within LLM module **304**. In addition to the material attribute context provided by material attribute details **302**, additional initialization context or procedures may be used to initialize LLM agents **306**. For example, LLM agents **306** may be initialized with context prompts instructing LLM agents **306** to assist a user in selecting an appropriate material for design being developed by the user. LLM agents **306** also may be initialized or implemented in ways that makes LLM agents **306** better suited to proposing filters for various material attributes. For example, LLM agents **306** may receive additional fine-tuning training on technical documents relevant to materials science and engineering. In other embodiments, LLM agents **306** may be implemented with a retrieval-augmented generation (RAG) procedure, which enables LLM agents **306** to reference specific reference documents when composing a response.

(32) After LLM agents **306** have been initialized with material attribute details **302**, LLM agents **306** receive the query prompt generated by query prompt generator **308**. Each LLM agent **306** processes the query prompt in the context of a corresponding material attribute and, in response, produces a range of material attribute values as a filter in a structured format. Each material attribute filter generated by LLM agents **306** is passed to query aggregator **310**, which combines the different material attribute filters to produce material query **206**.

(33) As described above, in some iterations, material selection module **112** may not generate any potential materials **210** that meet the user-specified design criteria. In such cases, the simulation

results from simulation module **114** are passed to reflection module **218**. Upon receiving those simulation results, reflection module **218** processes the simulation results and constructs a query prompt that prompts the LLM agents **306** to create new material attribute filters based on the simulation results. Each LLM agent **306** uses the chain-of-thought procedure to retain memory of different query prompts and context received during previous iterations. After receiving the query prompt with information about simulation results from reflection module **218**, each of LLM agents **306** produces material attribute filters in a similar manner to the first iteration, as described above, but with the addition of information from the simulation results. These material attribute filters are passed to query aggregator **310** to produce an updated material query **206**. Consistent with operations described above in conjunction with FIG. 2, the updated material query **206** produces a new set of potential materials **210** from material library **208**, and potential materials **210** are evaluated by simulation module **114** and compared to the user-specified design criteria. This process repeats, passing simulation results to reflection module **218** to generate and process updated material queries **206** until one or more potential materials **210** that meet the user-specified design criteria are found.

(34) As noted above, in some embodiments, rather than passing the simulation results to reflection module **218**, logic **216** may, instead, output a message informing the user that no appropriate materials could be identified. In such cases, the user can update the information included in assembly context **202**, and the updated assembly context **202** can be inputted into LLM chain-of-thought engine **204**, as previously described.

(35) FIG. 4 sets forth a flow diagram of method steps for determining appropriate materials for a design, according to various embodiments. Although the method steps are described in conjunction with the systems of FIGS. 1-3, persons skilled in the art will understand that any system configured to perform the method steps in any order falls within the scope of the present disclosure.

(36) As shown, method **400** begins at step **402**, where information is collected from the user and the CAD application **110** to produce assembly context **202**. Assembly context **202** includes structured information and context about a design being developed in CAD application **110**. In various embodiments, assembly context **202** includes information directly from the CAD environment (e.g., the design name, design volume, surface area) as well as a user-provided description of the intent or purpose of the design. Assembly context **202** also includes user-specified design criteria that specify the acceptable operating ranges of the design.

(37) At step **404**, LLM agents **306** are initialized with material attribute details **302**. Material attribute details **302** are a collection of material attributes, detailed natural language descriptions of what the material attributes represent, and the physical, chemical, and aesthetic properties that manifest for different material attribute values. Each material attribute details **302** corresponds to a different LLM agent **306**.

(38) At step **406**, assembly context **202** is passed to query prompt generator **308**, which produces a natural language LLM query prompt for the material attribute values that likely would meet the design criteria specified by the user.

(39) At step **408**, each LLM agent **306** processes the query prompt produced by query prompt generator **308** in the context of the material attribute corresponding to the particular LLM agent **306**. In response, each LLM agent **306** produces a range of material attribute values as a material attribute filter in a structured format. Each material attribute filter generated by LLM agents **306** is passed to query aggregator **308**, which combines the different material attribute filters to produce material query **206**.

(40) At step **410**, material query **206** is used to query material library **208**. Material library **208** includes a structured list of materials available for the design being developed and various material properties. Application of material query **206** produces a list of potential materials **210** corresponding to the filters in material query **206**.

(41) At step **412**, the potential materials **210** produced from querying material library **208** along

with assembly context **202** are passed to simulation module **114**. Simulation module **114** performs simulations of the design being developed based on potential materials **210**. For a given simulation, a different potential material **210** is used for the design being developed.

(42) At step **414**, the results from simulation module **114** are compared against the user-specified design criteria included in assembly context **202**. At step **416**, any potential material **210** that meets the user specified design criteria is returned as an appropriate material **214**, and method **400** then terminates. If none of potential materials **210** meets the design criteria, then the simulation results are passed to reflection module **218**, and the method **400** proceeds to step **418**.

(43) Again, in some embodiments (not shown in FIG. **4**), rather than passing the simulation results to reflection module **218**, logic **216** may, instead, output a message informing the user that no appropriate materials could be identified. In such cases, the user can update the information included in assembly context **202**, and the updated assembly context **202** can be inputted into LLM chain-of-thought engine **204**, as previously described.

(44) At step **418**, reflection module **218** processes the simulation results produced by simulation module **114** into updated an updated query prompt for LLM agents **306**. LLM agents **306** produce updated material attribute filters responding to the simulation results while maintaining context from previous iterations using a chain-of-thought procedure. The updated filters are aggregated by query aggregator **310** to produce an updated material query **206**. Method **400** then returns to step **410**, and iteration continues until at least one appropriate material **214** is produced.

(45) In sum, techniques are disclosed for filtering materials based on user intent capture with large language models (LLMs). In various embodiments, information is collected from both the user and the CAD environment about a given design. The information may include the design name, the physical dimensions and properties of the design, and user-provided descriptions of the intended uses of the design. These inputs make up the unified context of the design. A group of LLM agents is then initialized, where a different LLM agent is initialized for each material attribute being evaluated. A given LLM agent is initialized with the unified context of the design, along with descriptive details of the corresponding material attribute and specific material attribute values for each candidate material that is available to use for the design. In operation, each LLM agent parses the unified context of the design in the context of the material attribute corresponding to the LLM agent and generates appropriate filters for the materials that are available for the design. The filters are subsequently applied to the available candidate materials to generate a set of potential materials to use for the design. Each potential material is evaluated via simulation according to design criteria specified by the user, and the potential materials are ranked based on the simulation results. If one or more potential materials meet the specified design criteria, then those materials are designated as appropriate materials. If none of the potential materials meets the design criteria, then the results of the simulations are passed back to the LLM agents. The LLM agents are then prompted by the system to adjust the material parameters to meet the criteria. This process repeats until the design criteria are met and at least one material is designated as an appropriate material.

(46) One technical advantage of the disclosed techniques relative to the prior art is that the disclosed techniques enable suitable materials for designs to be automatically identified and evaluated without requiring users and designers to have the level of knowledge about material science, mechanics, mechanical engineering, or mechanical design that is typically required with conventional approaches. Accordingly, computer-aided design applications that incorporate the disclosed techniques can be accessed by a far broader range of users and designers to generate designs made of suitable materials than what conventional computer-aided design applications allow. Further, because the disclosed techniques can substantially reduce the amount of time required to identify suitable materials for designs, the disclosed techniques enable users and designers to more fully explore the overall design space, which can result in more optimized materials being selected for and incorporated into designs, thereby increasing overall design quality. These technical advantages provide one or more technological advances over prior art

approaches

(47) Any and all combinations of any of the claim elements recited in any of the claims and/or any elements described in this application, in any fashion, fall within the contemplated scope of the present invention and protection.

(48) The descriptions of the various embodiments have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments.

(49) Aspects of the present embodiments may be embodied as a system, method or computer program product. Accordingly, aspects of the present disclosure may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a “module,” a “system,” or a “computer.” In addition, any hardware and/or software technique, process, function, component, engine, module, or system described in the present disclosure may be implemented as a circuit or set of circuits. Furthermore, aspects of the present disclosure may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.

(50) Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

(51) Aspects of the present disclosure are described above with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the disclosure. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine. The instructions, when executed via the processor of the computer or other programmable data processing apparatus, enable the implementation of the functions/acts specified in the flowchart and/or block diagram block or blocks. Such processors may be, without limitation, general purpose processors, special-purpose processors, application-specific processors, or field-programmable gate arrays.

(52) The flowchart and block diagrams in the figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods and computer program products according to various embodiments of the present disclosure. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be

executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

(53) While the preceding is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims

1. A computer-implemented method for determining materials for computer-generated designs, the method comprising: generating a query prompt based on an assembly context; transmitting the query prompt to a plurality of large language model (LLM) agents for processing; receiving a plurality of material attribute filters from the plurality of LLM agents, wherein each LLM generates a different material attribute filter when processing the query prompt; combining the material attribute filters included in the plurality of material attribute filters to produce a material query; querying a material database using the material query to identify at least one potential material to use for a design; and evaluating simulation results to determine whether the at least one material is an appropriate material to use for the design, wherein the simulation results are generated from at least one simulation of the design using the at least one material.
2. The computer-implemented method of claim 1, wherein the assembly context includes structured information and context related to the design.
3. The computer-implemented method of claim 1, wherein each LLM agent included in the plurality of LLM agents corresponds to a different material attribute, wherein each LLM agent processes the query prompt in a context of the different material attribute corresponding to the LLM agent.
4. The computer-implemented method of claim 1, wherein the query prompt comprises a natural language query prompt for a plurality of material attribute values that likely would meet a plurality of design criteria specified for the design.
5. The computer-implemented method of claim 1, wherein the simulation results are evaluated based on at least one design criteria included in the assembly context.
6. The computer-implemented method of claim 5, wherein the at least one material satisfies the at least one design criteria, and further comprising designating the at least one material as an appropriate material to use for the design.
7. The computer-implemented method of claim 5, wherein the at least one material does not satisfy the at least one design criteria, and further comprising transmitting the simulation results to a reflection module for further processing.
8. The computer-implemented method of claim 7, wherein the reflection module processes the simulation results and generates an updated query prompt based on the simulation results.
9. The computer-implemented method of claim 8, wherein the reflection module transmits the updated query prompt to the plurality of LLM agents for processing.
10. The computer-implemented method of claim 9, further comprising receiving a plurality of updated material attribute filters from the plurality of LLM agents, wherein each LLM generates a different updated material attribute filter when processing the query prompt, and combining the different updated material attribute filters included in the plurality of material attribute filters to produce an updated material query.
11. One or more non-transitory computer-readable media including instructions that, when executed by one or more processors, cause the one or more processor to perform the steps of:

generating a query prompt based on an assembly context; transmitting the query prompt to a plurality of large language model (LLM) agents for processing; receiving a plurality of material attribute filters from the plurality of LLM agents, wherein each LLM generates a different material attribute filter when processing the query prompt; combining the material attribute filters included in the plurality of material attribute filters to produce a material query; querying a material database using the material query to identify at least one potential material to use for a design; and evaluating simulation results to determine whether the at least one material is an appropriate material to use for the design, wherein the simulation results are generated from at least one simulation of the design using the at least one material.

12. The one or more non-transitory computer-readable media of claim 11, wherein the assembly context includes at least one of information about the design taken directly from a computer-aided design environment, a user-provided description of an intent or a purpose of the design, or user-defined design criteria specifying acceptable operating ranges of the design.

13. The one or more non-transitory computer-readable media of claim 11, wherein each LLM agent is initialized with different material attribute details that include at least one of a natural language description of what one or more material attributes represent or at least one of a physical, a chemical, or an aesthetic property that manifests for a given material attribute value.

14. The one or more non-transitory computer-readable media of claim 11, wherein each LLM agent included in the plurality of LLM agents corresponds to a different material attribute, wherein each LLM agent processes the query prompt in a context of the different material attribute corresponding to the LLM agent.

15. The one or more non-transitory computer-readable media of claim 11, wherein evaluating the simulation results comprises comparing the simulation results to one or more design criteria to determine whether the at least one material satisfies the one or more design criteria.

16. The one or more non-transitory computer-readable media of claim 15, wherein the at least one material satisfies the one or more design criteria, and further comprising designating the at least one material as an appropriate material to use for the design.

17. The one or more non-transitory computer-readable media of claim 15, wherein the at least one material does not satisfy the one or more design criteria, and further comprising transmitting the simulation results to a reflection module for further processing.

18. The one or more non-transitory computer-readable media of claim 17, wherein the reflection module processes the simulation results and generates an updated query prompt based on the simulation results.

19. The one or more non-transitory computer-readable media of claim 18, wherein the reflection module transmits the updated query prompt to the plurality of LLM agents for processing.

20. The one or more non-transitory computer-readable media of claim 19, further comprising receiving a plurality of updated material attribute filters from the plurality of LLM agents, wherein each LLM generates a different updated material attribute filter when processing the query prompt, and combining the different updated material attribute filters included in the plurality of material attribute filters to produce an updated material query.

21. A system, comprising: one or more memories storing instructions; and one or more processors that are coupled to the one or more memories and, when executing the instructions, are configured to perform the steps of: generating a query prompt based on an assembly context; transmitting the query prompt to a plurality of large language model (LLM) agents for processing; receiving a plurality of material attribute filters from the plurality of LLM agents, wherein each LLM generates a different material attribute filter when processing the query prompt; combining the material attribute filters included in the plurality of material attribute filters to produce a material query; querying a material database using the material query to identify at least one potential material to use for a design; and evaluating simulation results to determine whether the at least one material is

an appropriate material to use for the design, wherein the simulation results are generated from at least one simulation of the design using the at least one material.
