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(54) **Title:** CONFIGURABLE DIGITAL TWINS OF CHEMICAL PRODUCTS

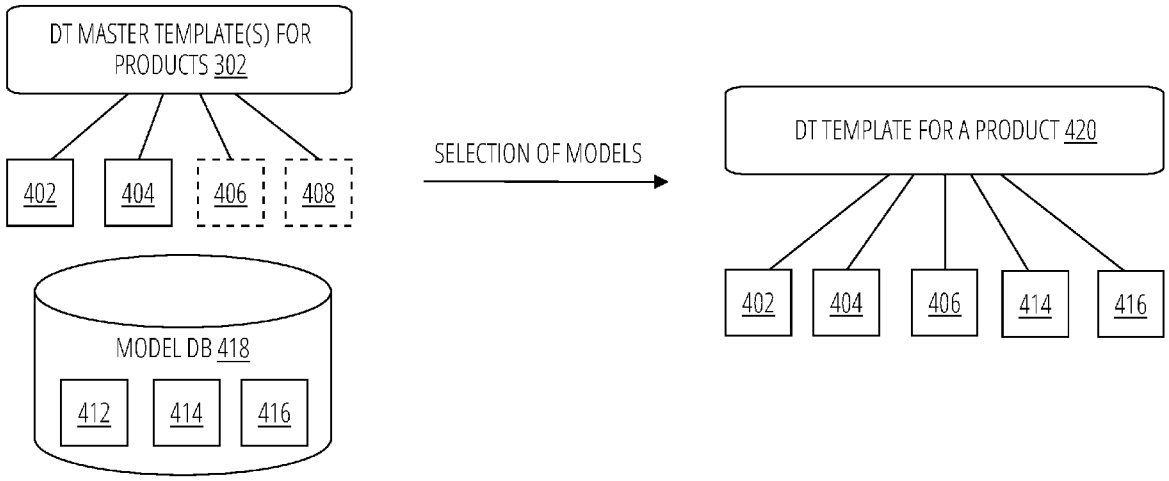

FIG. 4B

(57) **Abstract:** The present disclosure relates to an apparatus for generating a digital twin template associated with a product or a product class and a respective computer-implemented method and computer program element, an apparatus and system for generating a digital twin of a physical entity of a product and a respective computer-implemented method and computer program element, methods for providing a product associated with such a digital twin and respective apparatuses and a respective computer program element, a use of the digital twin, a product associated with such a digital twin, such a digital twin, and a computer-implemented method and apparatus for generating a digital access element associated with such a digital twin and a respective computer program element.

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CONFIGURABLE DIGITAL TWINS OF CHEMICAL PRODUCTS

TECHNICAL FIELD

The present disclosure relates to an apparatus for generating a digital twin template associated with a product or a product class and a respective computer-implemented method and computer program element, an apparatus and system for generating a digital twin of a physical entity of a product and a respective computer-implemented method and computer program element, methods for providing a product associated with such a digital twin and respective apparatuses and a respective computer program element, a use of the digital twin, a product associated with such a digital twin, such a digital twin, and a computer-implemented method and apparatus for generating a digital access element associated with such a digital twin and a respective computer program element.

TECHNICAL BACKGROUND

The production and supply chain of materials and products, such as chemical materials and chemical products, are heavily regulated to protect the human safety and the environment. Hence, manufacturers or importers of such materials and products need to document and provide information on this materials and products to meet regulatory requirements which differ depending on the material, the product, or the production, consumption or sales location. Currently, such information is provided in a variety of data formats, making exchange and sharing of such data cumbersome. Hence, there is a need to standardize and customize product data exchange and sharing.

SUMMARY OF THE INVENTION

In an aspect the disclosure relates to an apparatus for generating a digital twin template associated with a product or a product class, wherein the digital twin template defines one or more aspect models, each aspect model describing a specific set of properties of the product or the product class, the apparatus comprising one or more computing node, and one or more computer-readable media having thereon computer-executable instructions which, when executed by the one or more computing node, configure the apparatus to perform the steps of:

- receiving a request to generate the digital twin template, the request including data related to the product,
- providing a digital twin master template associated with one or more product classes, wherein the digital twin master template defines a plurality of aspect models,
- providing product data based on the data contained in the received request,
- optionally providing one or more further aspect model(s), wherein the one or more further aspect model(s) are different from the plurality of aspect models defined in the digital twin master template,
- generating - based on the provided product data - the digital twin template defining at least one aspect model defined in the digital twin master template and optionally at least one of the provided further aspect models.

In a further aspect the disclosure relates to a computer-implemented method for generating a digital twin template associated with a product or a product class, wherein the digital twin template defines one or more aspect models, each aspect model describing a specific set of properties of the product or the product class, the method comprising the steps of:

- receiving a request to generate the digital twin template, the request including data related to the product,
- providing a digital twin master template associated with one or more product classes, wherein the digital twin master template defines a plurality of aspect models,
- providing product data based on the data contained in the received request,
- optionally providing one or more further aspect model(s), wherein the one or more further aspect model(s) are different from the plurality of aspect models defined in the digital twin master template,
- generating - based on the provided product data - the digital twin template defining at least one aspect model from the digital twin master template and optionally at least one of the provided further aspect models.

In a further aspect the disclosure relates to an apparatus for generating a digital twin of a physical entity of a product, the apparatus comprising: one or more computing node; and one or more computer-readable media having thereon computer-executable instructions which, when executed by the one or more computing node, configure the apparatus to perform the steps of:

- receiving a request to generate the digital twin, the request including data related to the product,
- gathering data associated with the chemical product from one or more data sources based on the received data related to the product, wherein the data associated with the product includes at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product,
- providing a decentral digital twin identifier associated with the gathered data and optionally a data owner,
- providing a digital twin template to be applied to the gathered product data based on the data included in the received request, wherein the digital twin template has been generated by the apparatus for generating a digital twin template as disclosed herein or according to the computer-implemented method for generating a digital twin template as disclosed herein,
- generating - for each aspect model defined in the provided digital twin template - a digital twin data set by applying the respective aspect model to the gathered data,
- generating the digital twin including the provided decentral identifier and the generated digital twin data sets.

In a further aspect the disclosure relates to a computer-implemented method for generating a digital twin of a physical entity of a product, the method comprising the steps of:

- receiving a request to generate the digital twin, the request including data related to the product,
- gathering data associated with the product from one or more data sources based on the received data related to the product, wherein the data associated with the product includes at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product,
- providing a decentral digital twin identifier associated with the gathered data and optionally a data owner,
- providing a digital twin template to be applied to the gathered product data based on the data included in the received request, wherein the digital twin template has been generated by the apparatus for generating a digital twin template as disclosed herein or according to the computer-implemented method for generating a digital twin template as disclosed herein,
- generating - for each aspect model defined in the providing digital twin template - a digital twin data set by applying the respective aspect model to the gathered data,
- generating the digital twin including the provided decentral identifier and the generated digital twin data sets.

In a further aspect the disclosure relates to a system for generating a digital twin of a physical entity of a product, the system comprising:

- a data source layer configured to provide data associated with the product from one or more data source(s), wherein the data associated with the product includes the at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product,
- optionally a service layer configured to gather the data provided by the one or more data source(s), to optionally transform the gathered data, and to provide the gathered or transformed data,
- a consumer layer configured to consume the data provided by the one or more data sources or provided by the service layer and to generate the digital twin according to the computer-implemented method for generating a digital twin as disclosed herein, and
- optionally a connector layer comprising at least one decentral data providing network node configured to provide access to the generated digital twin and/or to least one digital twin data set contained in the digital twin by at least one decentral data consuming network node associated with a decentral network participant.

In a further aspect the disclosure relates to a system for providing a product associated with a digital twin, wherein the digital twin includes a decentral digital twin identifier and at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product, the system comprising:

- a production configured to produce the product from one or more input materials,

- a requestor configured generate a request to generate the digital twin, the request including data related to the product,
- an apparatus for generating a digital twin as disclosed herein or a system for generating a digital twin as disclosed herein for generating a digital twin of a physical entity of the product as disclosed herein, and
- an assignor configured to assign a physical identifier associated with the produced product to the decentral identifier included in the digital twin.

In a further aspect the disclosure relates to a method for providing a product associated with a digital twin, wherein the digital twin includes a decentral digital twin identifier and at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product, the method comprising:

- producing the product from one or more input materials by a production,
- generating the digital twin by the apparatus or system for generating a digital twin as disclosed herein or according to the computer-implemented method for generating a digital twin as disclosed herein, and
- assigning a physical identifier associated with the produced product to the decentral digital twin identifier included in the generated digital twin.

In a further aspect the disclosure relates to a computer-implemented method for providing a product associated with a digital twin, wherein the product is produced from one or more input materials by a production, the method comprising:

- receiving a request to generate the digital twin, the request including data related to the product,
- gathering data associated with the product from one or more data sources based on the received data related to the chemical product, wherein the data associated with the product includes the at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product,
- providing, based on a physical identifier associated with the product, a decentral digital twin identifier associated with the data associated with the gathered data and optionally a data owner, and assigning the provided decentral digital twin identifier to the physical identifier,
- providing a digital twin template to be applied to the gathered product data based on the data included in the received request, wherein the digital twin template has been generated by the apparatus for generating a digital twin template as disclosed herein or according to the computer-implemented method for generating a digital twin template as disclosed herein,
- generating - for each aspect model defined in the providing digital twin template - a digital twin data set by applying the respective aspect model to the gathered data,

- generating the digital twin including the provided decentral identifier and the generated digital twin data sets.

In a further aspect the disclosure relates to a computer-implemented method for providing access to a digital twin of a physical entity of a product, wherein the access to the digital twin by one or more decentral data consuming network node(s) associated with decentral participant(s) of a decentral network is controlled by a decentral data providing network node associated with the digital twin and wherein the digital twin is generated according to the computer-implemented for generating a digital twin as disclosed herein or by the apparatus or the system for generating a digital twin as disclosed herein, the method comprising:

- receiving at the decentral data providing network node associated with the digital twin a request to access the digital twin or a part thereof by the at least one decentral data consuming network node, wherein the request contains the decentral identifier associated with the digital twin,
- optionally authenticating and/or authorizing the request to access the digital twin or the part thereof by the decentral data providing network node,
- based on the decentral digital twin identifier and optionally the authentication and/or authorization, providing the decentral data consuming network node access to the digital twin or a part thereof by the decentral data providing network node.

In a further aspect the disclosure relates to a digital twin as generated according to the computer-implemented for generating a digital twin as disclosed herein or by the apparatus or the system for generating a digital twin as disclosed herein.

In a further aspect the disclosure relates to a use of the digital twin disclosed herein to process the product associated with the digital twin.

In a further aspect the disclosure relates to a product associated with a digital twin as disclosed herein.

In a further aspect the disclosure relates to a computer-implemented method for generating a digital access element associated with a digital twin of a product, said method comprising:

- generating the digital twin associated with the chemical product according to the computer-implemented method for generating a digital twin as disclosed herein or by the apparatus or system for generating a digital twin as disclosed herein,
- receiving a request to provide a decentral access element identifier associated with the digital twin of the product,
- in response to the request, providing the decentral access element identifier and generating the digital access element including the provided decentral access element identifier associated with the digital twin and access data,

- optionally providing the generated digital access element for access to the digital twin or a part thereof by a decentral data consuming network node under control by a decentral data providing network node associated with a data owner of the digital twin or the part thereof.

In a further aspect the disclosure relates to an apparatus for or generating an access element associated with a digital twin of a product, the apparatus comprising: one or more computing node; and one or more computer-readable media having thereon computer-executable instructions which, when executed by the one or more computing node, configure the apparatus to perform the computer-implemented method for generating a digital access element as disclosed herein.

In a further aspect the disclosure relates to a computer element, such as a computer readable storage medium, a computer program or a computer program product, comprising instructions, which when executed by a computing node or a computing system, direct the computing node or computing system to carry out the steps of the methods as disclosed herein.

In a further aspect the disclosure relates to a computer element, such as a computer readable storage medium, a computer program or a computer program product, comprising instructions, which when executed by the apparatuses or systems as disclosed herein, direct these apparatuses or systems to carry out steps these apparatuses or systems are configured to execute.

In a further aspect the disclosure relates to a digital twin template as generated by the apparatus as disclosed herein or by the computer-implemented method for generating a digital twin template as disclosed herein.

In a further aspect the disclosure relates to a use of the digital twin template as disclosed herein for generating a digital twin of a physical entity of a product.

Any disclosure, embodiments and examples described herein relate to the methods, the systems, apparatuses, digital twin templates, digital twins, products, uses and computer elements lined out above and below. Advantageously, the benefits provided by any of the embodiments and examples equally apply to all other embodiments and examples.

Embodiments

The methods, the systems, apparatuses, digital twin templates, digital twins, products, uses and computer elements disclosed herein provide an efficient and robust way to generate customized digital twin templates using a modular approach by selecting one or more aspect models from a digital twin master template defining a plurality of aspect models existing for products or product classes in a hierarchical order. By matching at least a part of the product data associated with a given product or product class with data points defined by the aspect model(s) included in the digital twin master template customized digital twin templates for a given product or product class can be generated. This customized

digital twin templates include at least some of the aspect models of the digital twin master template defining data points matching at least a part of the product data. The digital twin master template may hence represent a collection of aspect models which can be used to generate customized digital twin templates by selecting one or more aspect models based on the product data associated with a given product or product class. Generation of the digital twin template may further include selection of further aspect models not contained within the digital twin master template, allowing to consider product peculiarities not embraced by the aspect models included in the digital twin master template. This modular approach allows to select appropriate aspect models, e.g. aspect models required to describe properties, such as chemical and/or physical properties, of the product to fulfill regulatory requirements for produced products, from the digital twin master template and optionally further available aspect models, hence ensuring that the digital twins of products generated from such customized digital twin templates have a highly defined data structure simplifying data exchange and sharing while at the same time containing all relevant data required to meet the regulatory requirements. This modular approach significantly reduces the complexity associated with the generation of one single aspect model for each product or product class and allows to efficiently generate digital twin templates for a variety of different products or product classes. Moreover, the modular approach avoids issues regarding maintenance of a single large aspect model and the use of inappropriate semantic descriptions for a specific product or product class within such a single large aspect model, hence avoiding empty attributes due to missing product data in the digital twin.

Associating the digital twin generated from the digital twin template with a decentral identifier allows for simplified and customizable data sharing or exchange within the product ecosystem including the chemical industry, chemical supply chain participants, end-product producers and optionally end-product recycling chain participants. This way, a more reliable and efficient further processing of supplied raw materials by chemical industry, supplied chemical product by upstream participants of the chemical supply chain and/or recycling of the end-product by participants of the product recycling chain can be achieved, while the data remains in the ownership of the raw material supplier supplying the chemical industry, the chemical supplier supplying the upstream participant, the end-product producer and the recycling chain participant, respectively. By including one or more authorization mechanisms, the data sharing or exchange can be conducted in a more flexible manner with multiple data consuming network nodes from different participants of the chemical supply chain accessing the data contained in the digital twin.

It is an object of the present invention to provide a simplified, standardized and customizable sharing or exchange of product data associated with a variety of different products within the product ecosystems including the chemical industry, chemical supply chain participants, end-product producers and optionally end-product recycling chain participants .

These and other objects, which become apparent upon reading the following description, are solved by the subject matters of the independent claims. The dependent claims refer to preferred embodiments of the invention.

In the following, embodiments of the present disclosure will be outlined by ways of examples. It is to be understood that the present disclosure is not limited to said embodiments and/or examples.

In an embodiment, the digital twin of the product may be a digital representation of a physical entity of the product with a defined semantic description of said physical entity of the product. The digital twin of the physical entity of the product is hence a digital version of said physical entity. Once created, the digital twin may be used to represent the physical entity of the product in a digital representation of a real-world system. The digital twin may be uniquely linked to the physical product via at least the decentral digital twin identifier. The digital twin may be created such that it is identical in form and behavior of the corresponding product. Additionally, the digital twin may mirror the properties of the product during its lifetime. For example, sensors may capture real-time (or near real-time) data, such as transport data or use data, from the physical product to relay it back to a remote digital twin. Sensor may include hard sensors and/or soft sensors. The digital twin may then be updated to maintain its correspondence to the physical entity of the product. Hence, the digital twin may at any time represent the current state of the physical entity of the product. The digital twin may contain one or more digital twin data sets. At least one digital twin data set may contain at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product. Each digital twin data set may contain defined product data. Each digital twin data set may be associated with the decentral digital twin identifier. Each digital twin data set may further be associated with a digital twin data set identifier. This allows to uniquely identify each digital twin data set contained in the digital twin by using the digital twin data set identifier associated with said digital twin data set. The digital twin may comprise the decentral digital twin identifier, the digital twin data set(s) and digital twin data set identifier(s) associated with the digital twin data set(s). The digital twin may further contain a product identifier.

In an embodiment, the aspect model (also denoted as data model) may contain a semantic description of the respective digital twin data set associated with the digital twin. The semantic description may include the structure of at least a portion of the digital twin data set, and/or properties of the digital twin data set. The properties of the digital twin data set may include data types. The properties of the digital twin data set may include possible or allowable values and/or value ranges. The properties of the digital twin data set may be a physical unit of parameter(s) described by values contained in the digital twin data set. The properties of the digital twin data set may include one or more attribute(s). The aspect model may define (i) the data structure of at least a part of a digital twin, such as the digital twin data set, resulting from application of the aspect model to product data associated with physical entity of the product or product class and (ii) one or more data points included in such part(s) of the digital twin. The

data point(s) may define physical and/or chemical properties of the product or product class. The data point(s) may define data associated with the production of the product. The data point(s) may define data associated with the use of the product and/or the disposal or recycling of the product. The aspect model may hence act as a blueprint for a given digital twin data set resulting from applying such aspect model to the product data. The aspect model may hence correspond to a machine-readable semantic description of the digital twin or a part thereof. The data structure may correspond to a blueprint or template for organizing data, such as product data, while the data point(s) may define the actual content of the data. The data structure may define allowed data types, such as numbers, strings, Booleans, etc., and/or relationships such as linear order in an array, parent-child relationship in a tree. The aspect model may further specify processing rules associated with one or more data point(s) and/or the digital twin data set. Processing rules may include transformation rules for transforming product data from one format into another format and/or calculation rules for performing calculations on product data. The In an embodiment, digital twin master template may refer to a superset of aspect models defined for one or more product classes. For instance, a superset of aspect models may be associated with the product class “chemical product” and may contain a plurality of aspect models defined for chemical products. The superset of aspect models may contain a plurality of aspect models. The aspect models contained in the superset may be different from each other. The plurality of aspect models may include at least two different aspect models. The digital twin master template may contain a tree structure comprising a root entity or root node connected to the plurality of aspect model(s). The digital twin master template may include a hierarchical tree structure with a set of connected nodes represented by aspect models. Each aspect model in the tree may be connected to one or more child node(s) (e.g. sub aspect model(s)) and to exactly one parent node, except for the root node, which has no parent node or aspect model. The root entity may correspond to the product class(es) the digital twin master template is associated with. For instance, a digital twin master template associated with the product class “chemical material” may define the chemical material as root entity.

In an embodiment, digital twin template may refer to a subset of aspect models with respect to the number of aspect models defined in the digital twin master template. Hence, the digital twin template may contain a selection of aspect models defined in the digital twin master template. The digital twin template may further contain at least one further aspect model not defined in the digital twin master template. This allows to customize the digital twin template such that it contains all aspect models required to appropriately describe the physical product in the digital world. The digital twin template may be used to generate the digital twin or a part thereof associated with a physical entity of the product. The digital twin or the part thereof may be generated by applying the digital twin template to product data associated with the physical entity of the product.

In an embodiment, the product class may represent a generic term applicable to a plurality of specific products. For instance, the product class “polymer” may be applicable to all chemical compounds

representing a polymer. In another instance, the product class “automotive seat” may be applicable to all products representing an automotive seat.

In an embodiment, the computing node may include at least one hardware processor and a memory. The computing node may include program code. The program code may be referred to as an executable component, executable instructions, computer-executable instructions or instructions. The structure of the executable component may exist on a computer-readable medium such that, when interpreted by one or more processors of the computing node, the computing node is caused to perform the functions described herein. The processor of each computing node may direct the operation of each computing node in response to having executed computer-executable instructions that constitute an executable component.

In an embodiment, the product is a chemical product. The chemical product may be a chemical product obtained from at least one chemical reaction. The chemical product may include natural chemical products. Natural chemical products may include any chemical product that is produced by nature without human interaction or intervention, i.e. any unprocessed chemical substance that is found in nature, such as chemicals from plants, micro-organisms, animals, the earth and the sea or any chemical substance that is found in nature and extracted using a process that does not change its chemical composition. Natural chemical products may include biologicals like enzymes as well naturally occurring inorganic or organic chemical products. Natural chemical products may be isolated and purified prior to their use or they can be used in unisolated and/or unpurified form. Chemical products may be synthetic chemical products. Synthetic chemical products may include chemical products produced with human interaction or intervention. Synthetic chemical products may be produced with the same chemical reactions occurring in nature or with different chemical reactions. Chemical products may be any inorganic or organic chemical product obtained by reacting inorganic and/or organic chemical reactants. The inorganic and organic chemical reactants may be natural chemical products or may be synthetic chemical products. Chemical reactions may include any chemical reaction commonly known in the state of the art in which the reactants are converted to one or more different chemical products. Chemical reactions may involve the use of catalysts, enzymes, bacteria, etc. to achieve the chemical reaction between the reactants. The chemical product may include a raw material. The chemical product may include a chemical material produced by reacting at least two raw materials and/or intermediate products.

The chemical product may be produced by a chemical production from one or more materials. The materials may include raw materials, intermediate chemical products or chemical products received from a supplier. The chemical production may be a chemical production network including multiple interlinked processing steps. The chemical production network may be an integrated chemical production network with interrelated production chains. The chemical production network may include multiple different production chains that have at least one intermediate product in common. The chemical production network may include multiple stages of the chemical value chain. The chemical production network may

include multiple production chains that produce from one or more inbound material(s) as input chemical products as output. The chemical production network may include multiple tiers of a chemical value chain. The chemical production network may include a physically interconnected arrangement of production sites. The production sites may be at the same location or at different locations. In the latter case, the production sites may be interconnected by means of dedicated transportation systems such as pipelines, supply chain vehicles, like trucks, supply chain ships or other cargo transportation means. The chemical production may be controlled by an operating system. The operating system may be configured to perform the methods disclosed herein. The operating system may comprise the apparatuses and systems disclosed herein.

In an embodiment, the product is a component, a component assembly, an end product, an end-of-life product, or a recycled material. The component may be produced using one or more chemical products. The recycled material may include any material obtained upon performing at least on recycling step of a recycling chain associated with the product. The-end-of-life product may include products which can no longer be used as intended and are designated as waste products.

In an embodiment, the data related to the product includes a product identifier, a product class or a combination thereof. The product identifier may include a batch number, a product name, a product ID, a part number, a LOT number or a combination thereof. The LOT number may be assigned to the product on production.

In an embodiment, the set of properties described by each aspect model defined in the digital twin template and/or the digital twin master template may include chemical and/or physical properties of the product or product class. In an embodiment, the set of properties described by at least a part of the aspect models defined in the digital twin template and/or the digital twin master template may include chemical and/or physical properties of the product or product class. The chemical property may be a property of the product that becomes evident during, or after, a chemical reaction. Hence, the chemical property may be any quality that can be established only by changing the chemical identity of the product. Examples of chemical properties include heat of combustion, enthalpy of formation, toxicity, chemical stability in a given environment, flammability, oxidation state(s), ability to corrode, combustibility, acidity and basicity, chemical product composition, recyclate content used for producing or manufacturing the chemical product, bio-based content used for producing or manufacturing the chemical product, renewable content used for producing or manufacturing the chemical product and pH value. The physical property may be any property that is measurable and may hence be obtained using a sensor. Hence, the value of a physical property describes a state of the product. Examples of physical properties include absorption, brittleness, boiling point, capacitance, color, concentration, density, ductility, distribution, efficacy, elasticity, electric charge, electrical conductivity, electrical impedance, electric potential, flow rate, fluidity, hardness, heat capacity, inductance, intrinsic impedance, luminance, luminescence, luster, mass, melting point, opacity, permeability, permittivity, plasticity, pressure, radiance, resistivity, reflectivity, refractive

index, solubility, specific heat, strength, stiffness, temperature, tension, thermal conductivity, thermal resistance, viscosity, volume and wave impedance.

In an embodiment, the digital twin master template is provided from a database. The database may be a central database. The database may be part of a decentral network. The decentral network may be a decentral peer-to-peer communication network. The decentral network may include participant network nodes associated with participants of the product ecosystem and may be configured to perform data transactions. The decentral participant node may comprise a network node of the decentral network. The network nodes associated with participants of the product ecosystem may be associated with raw chemical product supplier, intermediate chemical products manufacturer, intermediate part manufacturer, component manufacturer, component assembly manufacturer, end-product manufacturer, or participant(s) of the recycling chain associated with the end-product. The data transactions may be based on a transaction protocol including authentication and/or authorization mechanism(s). Based on the authentication and/or authorization mechanism(s) a peer-to-peer communication between decentral network nodes associated with participants of the product ecosystem may be established. The one or more authentication mechanism(s) may be associated with or linked to the decentral digital twin identifier and/or the decentral access element identifier. The one or more authentication mechanism(s) may be associated with or linked to decentral participant identifier(s) associated with participants of the decentral network.

The digital twin master template stored in the database may be accessed by a decentral data consuming network node. The decentral data consuming network node may be part of a decentral system. The decentral data consuming network node may be associated with the participant of the product ecosystem generating the digital twin template. The decentral data consuming network node may comprise computer-executable instructions for accessing and/or processing data within the decentral network. The stored digital twin master template may be provided by a decentral data providing network node associated with the database. The decentral data providing network node may be part of the decentral network. The decentral data providing network node may comprise computer-executable instructions for providing and/or processing data within the decentral network. The decentral configuration allows for more efficient use of computing resources.

In an embodiment, the digital twin master template includes the plurality of aspect models and/or includes one or more digital representations pointing to the plurality of aspect models. The digital representation(s) may include an endpoint for data exchange or sharing (resource endpoint) or an endpoint for service interaction (service Endpoint), that is uniquely identified via a communication protocol. The digital representation(s) may be regarded as locator(s) indication the location or dedicated data storage(s) where the respective aspect model is stored. Use of digital representations allows to reduce the data contained in the digital twin master template and hence also the amount of data associated with the provision of the digital twin master template. Moreover, use of the digital representation(s) allow a greater

flexibility with respect to amendments of aspect model(s) contained in said digital twin master template since only the respective aspect model needs to be amended without having to amend the digital twin master template. Use of digital representation(s) within the digital twin master template hence allows to reduce the amount of data contained in said template to a minimum, allowing more efficient data transfer and maintenance of the digital twin master template.

In an embodiment, the digital twin master template defines relationships between one or more aspect models of the plurality of aspect models defined in said master template. The relationships may define the mandatory aspect models and the non-mandatory aspect models. The relationships may define a tree structure for the plurality of aspect models defined in the digital twin master template. The tree structure may include one or more levels resulting in a hierarchical order of the aspect models defined in said digital twin master template. The relationship between aspect models on a higher tree level with respect to aspect models in the following lower tree level may be described as a parent - child relationship, e.g. aspect models in the higher tree level may be denoted as parent aspect models while aspect models associated with said parent aspect models in the following lower tree level may be denoted as child aspect models. The relationship(s) may be defined by relationship representation(s) specifying parent aspect model(s) associated with child aspect model(s) and/or child aspect model(s) associated with a respective parent aspect model. The relationship representation may specify the relationship type between the respective parent aspect model child aspect models associated with the respective parent aspect model. For instance, the relationship representation associated with the root entity (or root node) may specify the child aspect models associated with said root entity and the relationship types between the root entity and each respective child aspect model. The relationship type may specify whether respective child aspect models may be mandatory aspect models or non-mandatory aspect models. Mandatory aspect models may be defined by a 1:1 or a 1:at least one relationship type. Non-mandatory aspect models may be defined by a 1:0 or more relationship type. The relationship type may specify the number of child aspect models associated with the parent aspect model. For instance, a 1:1 relationship type may be used to define that exactly one child aspect model is associated with the parent aspect model. In another instance, a 1:many relationship type may be used to define that more than one child aspect model may be associated with the respective parent aspect model. The relationship representation may be associated with the respective parent aspect model. The relationship representation may be associated with the respective child aspect models.

In an embodiment, the plurality of aspect models includes at least one mandatory aspect model and optionally at least one non-mandatory aspect model. Mandatory aspect models may include aspect models which need to be selected from the plurality of aspect models included the digital twin master template upon generation of the digital twin template. Defining aspect models as mandatory aspect models within the digital twin master template ensures that data required by legal and/or regulatory frameworks is contained within the digital twin generated from the respective digital twin template, hence avoiding provision of further data along with the digital twin. This allows to standardize exchange and

sharing of product data within the product ecosystem. Non-mandatory aspect models may include aspect models which may be selected from the plurality of aspect models included the digital twin master template upon generation of the digital twin template. Defining aspect models as non-mandatory aspect models allows a flexible and modular approach to generate the digital twin template because aspect models not being suitable for the specific product or product class the digital twin template is to be generated for do not have to be selected and hence are not contained in the digital twin template. This avoids the presence of empty data fields due to the use of aspect models defining data types and attributes not available or applicable to the specific product or product class. Mandatory aspect models and non-mandatory aspect models may be defined via relationship representations and associated relationship types as previously described.

The at least one mandatory aspect model may include aspect model(s) defining digital twin data, aspect model(s) defining digital twin template data, aspect model(s) defining product safety data, aspect model(s) defining product producer data, aspect model(s) defining identification data of the product, aspect model(s) defining product composition data, aspect model(s) defining product parameter data, aspect model(s) defining product handling data, aspect model(s) defining product disposal data, or a combination thereof.

Non-mandatory aspect models may include aspect model(s) defining product packaging data, aspect model(s) defining certificate of analysis data associated with the product, aspect model(s) defining emission data associated with the product, aspect model(s)defining production data associated with the product, aspect model(s) defining technical data associated with the product, aspect model(s) defining certificate data associated with the product, aspect model(s) defining data on the supplier of materials used to produce the product, aspect model(s) defining data on the supply of the product to a consumer of the product, aspect model(s) defining data on the registration of the product, or a combination thereof.

In an embodiment, the product data includes data or classes of data to be included in a digital twin associated with the product. Classes of data may include data related to the use of the product, data related to the production of the product, product composition data, product property data, data associated with the ecological profile of the product, regulatory data associated with the product, certificates associated with the product, or a combination thereof. The product data may further include one or more product identifiers and/or the product name. The at least one product identifier may correspond to the product identifier(s) contained in the received request.

Data related to the use of the product may include data related to further processing of the product, for example by using the product as reactant in further chemical reaction(s) and/or within manufacturing processes. Data related to the use of the product may include data related to the handling and/or disposal of the product. Data related to the use of the product may include data related to recycling processes associated with the product. Data related to the production of the product may comprise any data related

to the production of the product at any stage in the product value chain. Said data may include production data from the production of the product. Production data may include monitoring and/or control data associated with the production of the product. Production data may include measurement data related to a product quality at any stage in the product value chain.

Product property data may include measured and/or determined chemical and/or physical properties of the product previously described. The measured at least one physical and/or chemical property may be obtained by sensors configured to measure the physical and/or chemical property. The sensor may be included in a measuring device. The sensor may correspond to the measuring device. For example, the physical and/or chemical property may include a property provided by sensors of a mobile device such as a camera, or measurement devices configured to measure at least one physical and/or chemical property.

Data associated with the ecological profile of the product may include or correspond to emission data of the product, recyclate content data of the product, bio-based content data of the product, renewable content data of the product, or a combination thereof. Emission data may comprise any data related to environmental footprint. The environmental footprint may refer to an entity and its associated environmental footprint. The environmental footprint may be entity specific. For instance, the environmental footprint may relate to a product, a company, a process such as a manufacturing process, a raw material or basic substance, a chemical product or material, a component, a component assembly, an end product, combinations thereof or additional entity-specific relations. Emission data may include data relating to the carbon footprint of the product or a Product Carbon Footprint (PCF). Emission data may include data relating to greenhouse gas emissions e.g. released in production of the product. Emission data may include data related to greenhouse gas emissions. Greenhouse gas emissions may include emissions such as carbon dioxide (CO_2) emission, methane (CH_4) emission, nitrous oxide (N_2O) emission, hydrofluorocarbons (HFCs) emission, perfluorocarbons (PFCs) emission, sulfur hexafluoride (SF_6) emission, nitrogen trifluoride (NF_3) emission, combinations thereof and additional emissions. Emission data may include data related to greenhouse gas emissions of an entities or companies own operations (production, power plants and waste incineration). Scope 2 may comprise emissions from energy production which is sourced externally. Scope 3 may comprise all other emissions along the value chain. Specifically, this may include the greenhouse gas emissions of raw materials obtained from suppliers. Product Carbon Footprint (PCF) may sum up greenhouse gas emissions and removals from the consecutive and interlinked process steps related to a particular product. Cradle-to-gate PCF may sum up greenhouse gas emissions based on selected process steps: e.g. from the extraction of resources up to the factory gate where the product leaves the company. Such PCFs may be called partial PCFs. In order to achieve such summation, each company providing any products may provide the scope 1 and scope 2 contributions to the PCF for each of its products. Recyclate content data, bio-based content data and renewable content data may comprise any data related to the recyclate content or the bio-based content or the renewable content used for producing or manufacturing a physical entity of the product.

Regulatory data associated with the product may include or correspond to product declaration data, product safety data, certificate of analysis data associated with the product, or a combination thereof.

In an embodiment, the product data is provided from one or more databases based on the data contained in the received request. For instance, the data may be requested from the database(s) or retrieved from the database(s) based on product identifier(s) contained in the received request. The database(s) may be associated with a production producing the product from one or more materials entering the production. The database(s) may be distributed data sources. A distributed data source may be a collection of data stored at different sites of a computer network. Each site might expose a degree of autonomy, providing services for the execution of local applications, but also participating in the execution of a global application. For instance, a distributed data source may be a distributed database. A distributed database can be created by splitting and scattering the data of an existing database over different sites or by federating together multiple existing databases. Each data source may contain only a fragment of the product data. This leads to a fragmentation of said data. Two common types of data fragmentation are horizontal fragmentation, wherein (possibly overlapping) subsets of data tuples are stored at different sites; and vertical fragmentation, wherein (possibly overlapping) subtuples of data tuples are stored at different sites. More generally, the product data may be fragmented into a set of relations (tables of a relational database, distributed across multiple sites).

In an embodiment, the at least one further aspect model is provided from a database. The database may be a central database. The database may be part of a decentral network as previously described. The further aspect model(s) stored in the database may be accessed by a decentral data consuming network node as previously described. The decentral data consuming network node may be associated with the participant of the product ecosystem generating the digital twin template. The stored further aspect model(s) may be provided by a decentral data providing network node associated with the database as previously described.

In an embodiment, the at least one further aspect model is provided based on the provided product data. For instance, the provided product data may be used to determine further aspect model(s) matching said product data or a part thereof. The determined further aspect model(s) may then be provided. Use of further aspect model(s) not defined in the digital twin master template allows to generate digital twin templates for products in a flexible way such that the digital twin of the product generated using said digital twin templates contains all required data. Hence, available aspect model(s) (e.g. aspect models defined in the digital twin master template and further aspect models) may be combined in a modular approach to design a digital twin template for a specific product or product class which allows to generate digital twins for such product or product class containing all data required to fulfill at least the regulatory requirements associated with such product or product class. The modular approach further allows to consider requirements imposed by downstream participants of the product value chain, such as

consumers of the product and further downstream participants, and/or well as participants of a recycling chain associated with the product. This allows to ensure that the digital twin template contains all aspect models which are necessary to fulfill not only the regulatory requirements but also further requirements imposed by participants of the product ecosystem.

In an embodiment, generating the digital twin template includes selecting at least one aspect model from the plurality of aspect models defined in the provided digital twin master template and optionally selecting at least one of the provided further aspect models based on the provided product data. Selecting at least one aspect model from the plurality of aspect models defined in the digital twin master template may include mapping the provided product data to aspect model(s) defined in the digital twin master template. The mapping may include matching the provided product data to aspect model data associated with the aspect models defined in the digital twin master template. The mapping may include matching the provided product data to data point(s) chemical and/or physical properties defined by the aspect models included in the digital twin master template. In case the provided product data may map on one or more aspect model(s) defined in the digital twin, said aspect model(s) may be selected. Selecting at least one aspect model from the provided further aspect models may include mapping the provided product data to the further aspect model(s) as described previously.

In an embodiment, the digital twin template includes at least one of the aspect models defined in the digital twin master template and optionally at least one of the provided further aspect models and/or includes one or more digital representations defined in the digital twin master template and optionally one or more digital representations pointing to at least one of the provided further aspect models. The digital twin template may hence contain a subset of the aspect models defined in the digital twin master template. The digital twin template may contain additional aspect model(s) not defined in the digital twin master template. This allows to generate a digital twin template containing all aspect models which are necessary to fulfill the regulatory requirements as well as requirements imposed by participants of the product ecosystem.

In an embodiment, the generated digital twin template may be provided. Providing the generated digital twin template may include providing said digital twin template to a database. The digital twin template may be interrelated with data associated with the product and/or with product data in said database. For instance, the digital twin template may be interrelated with one or more identifier(s) associated with the product or the product class in said database. Providing the digital twin template may include providing said template via a communication interface for display. This allows to control the aspect models defined in said template to ensure that all required aspect models are defined properly. This avoids missing data in the digital twin generated from said digital twin template and hence ensures that digital twins generated from said digital twin template contain all required data.

In an embodiment, the apparatus for generating the digital twin template further performs the step of updating the digital twin master template with one or more further aspect models defined in the generated digital twin template. Updating may include defining the one or more further aspect model(s) in the digital twin master template. The updated digital twin master template may be provided to a database, such as the database storing digital twin master templates as previously described. Updating the digital twin master template with further aspect models allows to increase that number of aspect models available to generate digital twin templates and to share aspect models generated for a specific product or product class with other participants of the product ecosystem. This may result in more efficient generation of digital twin templates due to the increased number of available aspect models that can be used for the modular approach during the generation of the digital twin template.

In an embodiment, the one or more of the selected further aspect models defined in the generated digital twin template may be provided for updating the digital twin master template. The further aspect model(s) may be provided to a third party, such as a party operating the database storing the digital twin master templates, and the third party may use at least part of the provided aspect models to update the respective digital twin master template.

The digital twin template as generated by the apparatus or method disclosed herein may be used to generate further digital twin template(s) for different products or product classes. Hence, the generated digital twin template(s) may serve as digital twin master templates for further products or product classes. This allows to reuse existing digital twin templates defining a reduced number of aspect models with respect to the digital twin master template, hence reducing the number of aspect models that have to be mapped to the product data during generation of the further digital twin template.

The digital twin template as generated by the apparatus or method disclosed herein may be used to generate a digital twin of a physical entity of a product. For instance, a digital twin template associated with a product or a product class as generated by the apparatus or by the method disclosed herein may be used to generate a digital twin of such product or a product belonging to such product class.

The digital twin may include a decentral digital twin identifier and one or more digital twin data set(s). The decentral digital twin identifier may comprise any unique identifier uniquely associated with the digital twin and/or digital twin data set(s), and optionally a data owner. The decentral digital twin identifier may connect the physical entity of the product to the digital twin. The decentral digital twin identifier may include one or more Universally Unique Identifier(s) (UUID(s)) or Digital Identifier(s) (DID(s)). The one or more DID(s) and/or UUID(s) may be associated with the digital twin and/or the digital twin data set. The one or more DID(s) and/or UUID(s) may further be associated with the product. The decentral digital twin identifier may be generated by the data owner or on behalf of the data owner of the digital twin data. The decentral digital twin identifier may include authentication information. Via the decentral digital twin identifier and its unique association with the digital twin (and hence with the product) and optionally the

data owner, access to the digital twin generated from said data or access to parts of the digital twin, such as digital twin data set(s) contained in the digital twin, may be controlled by the data owner. This contrasts with central authority schemes, where identifiers are provided by such central authority and access to data is controlled by such central authority. Decentral in this context refers to the usage of the decentral identifier(s) in implementations as controlled by the data owner. The decentral digital twin identifier may include or be associated with one or more identifier(s) used in the decentral network and allowing for data exchange via the decentral network. For instance, the decentral digital twin identifier may include or be associated with digital twin data set identifier(s) of digital twin data sets, such as UUID(s) of digital twin data set(s). Any combination of UUID(s) and DID(s) may be possible. For instance, the decentral digital twin identifier may be a DID while the digital twin data identifier(s) may be UUID(s). In another instance, the decentral digital twin identifier, and the digital twin data identifier(s) may be UUIDs. Data exchange may include discovery of the decentral identifier and optionally identifier(s) associated with said decentral identifier for participant nodes of the decentral network, authentication of participant nodes of the decentral network and/or authorization of data transfers via a peer-to-peer communication between participant nodes of the decentral network. The decentral digital twin identifier may be associated with any participant of the product ecosystem including raw chemical product supplier, intermediate chemical products manufacturer, intermediate part manufacturer, component manufacturer, component assembly manufacturer, end product manufacturer or recycling chain participant. The decentral digital twin identifier may be associated with a machine, a system, or a device used for producing the raw material, the basic substance, the chemical product, the intermediate product, the component, the component assembly or the end product or for performing at least one recycling step of a recycling chain associated with the product, or a collection of such machine(s), device(s) and/or system(s).

The decentral digital twin identifier may be linked to other decentral product identifier(s) according to a physical relation of the product entity with other physical entities e.g. those produced using the product or those produced from the product. This way decentral participant node(s) of the decentral network may be able to interpret the relation of the decentral digital twin identifier corresponding to the physical relation of the physical chemical entity to other physical entities. The linking of the decentral digital twin identifier with other decentral product identifier(s) allows to determine the decentral participant node(s) storing the collected data associated with the use of the product or the determined physical and/or chemical property. The collected data and/or the determined chemical and/or physical property may be provided by said decentral participant node(s) and may be stored within the digital twin. For instance, a new data set may be generated by applying an aspect model associated with the use of the product and said new data set may be used to update the digital twin.

The decentral digital twin identifier may be associated with a physical entity of the product. The decentral digital twin identifier may be associated with the physical entity of the product the digital twin is generated for. The decentral digital twin identifier may be associated with the physical entity of the product the generated digital twin data sets are associated with.

The decentral digital twin identifier may or may be assigned to a physical identifier connected to the product. The connection of the physical identifier with the product may be provided by means of physical connection to the physical product or physical entity. For instance, the physical identifier may be connected with the physical entity of the product. The physical identifier may have one-to-one correspondence to a virtual identity or to a physical identity by means of a physical connection to the physical entity. The physical identifier may be physically attached to the product via an identifier element. Physical identifier or physical identifier element may refer to any virtual or physical arrangement that associates the decentral identifier with the product. The physical identifier may be any identifier for the produced product, such as a batch number or a part number. The physical identifier element may comprise a passive or active element, e.g. QR-code, RFID-tag, but is not limited thereto. The physical identifier element may be a physical identifier physically connected to the product. The identifier element may include markers embedded in materials, a bar code, a QR-Code, a tag like a RFID tag or similar physical arrangement that allows to digitally identify the product.

The data owner may include an entity generating the data associated with the product and/or the data owner is the data owner of the data associated with the product and/or of the digital twin data set(s). The data generating node may be coupled to the entity owning the physical entity of the products from or for which data is generated. The data, in particular the data associated with the product, may be generated by a third-party entity on behalf of the entity owning the physical entity of the products from or for which data is generated. The data owner may be the product producer. The data owner may hence directly or indirectly own the data associated with the product. The data associated with the product may be stored in a data base of or associated with the data owner. The data associated with the product may be stored in a data base of or under control by the data owner. The data associated with the product may be stored in a data base accessible by the data owner. The data owner may control access to the data associated with the product, for instance via a decentral data providing network node associated with the data owner. The data associated with the product may be associated with the data owner. The data owner may be the owner of the data associated with the product or the product data owner. In this sense, the data owner is to be construed broadly as the entity having access to the data associated with the product and controlling access by decentral data consuming network nodes of the decentral network to the digital twin or a part thereof generated using said data associated with the product.

The digital twin data set may correspond to the data structure obtained upon applying the respective aspect model to the gathered data associated with the physical entity of the product. The digital twin data set may include values and/or value ranges defined in the aspect model used to generate the digital twin data set. The digital twin data set may be a data set suitable for representing at least part of the gathered data. The digital twin data set may represent at least part of the gathered data. The digital twin data set may comprise a subset of the gathered data. The digital twin data set may refer to a selection of data points within the gathered data. Hence, each digital twin data set contains the data structure and data defined by the aspect model used for its generation. This ensures that each digital twin data set has a

defined structure and contains defined data, thus allowing to simplify data exchange and processing of the exchanged data on products. The respective aspect model may be defined in the generated digital twin template. Hence, the digital twin data set(s) contained in the digital twin may be generated by applying the aspect model(s) defined in the respective digital twin template to the gathered data. The digital twin data set may include a digital twin data set identifier. The digital twin data set may include a product identifier. This allows to associate the digital twin data set to a specific product. The digital twin data set(s) may be assigned to the decentral digital twin identifier. The digital twin data set(s) may be linked to the decentral digital twin identifier. Use of a combination of decentral digital twin identifier and digital twin data set identifier allows to retrieve the respective digital twin data set (e.g. a part of the generated digital twin), thus avoiding retrieval of the complete digital twin if only access to a specific digital twin data set of the digital twin is requested. Moreover, this allows to control the access to the digital twin more granular, because access may be controlled on the digital twin data set level.

The digital twin may include at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product. The digital twin may include at least two different measured and/or determined physical and/or chemical properties being present in different digital twin data sets. Data points within different data sets may overlap. The data associated with the production of the product may be collected before, during and/or after production of the product. The collected product data may be used to determine at least one physical and/or chemical property of the produced product. For instance, emission data of the product may be determined based on product data collected during production of the product. Data associated with the production of the product may include production data from the production of the product. Data associated with the production of the product may include monitoring and/or control data associated with the production of the product. The data associated with the use of the product may be collected via at least one identifier associated with the product. The data may be collected during and/or after use of the product. Collected data may include at least one measured physical and/or chemical property of the used product. The measured physical and/or chemical property may include the chemical and/or physical properties described previously. The data may be collected with a suitable sensor configured to measure the chemical and/or physical property. The sensor data may be interrelated with the identifier associated with the product. The chemical and/or physical property determined from the sensor data may be interrelated with the identifier associated with the product. The identifier may include the product identifier. The identifier may include the decentral digital twin identifier.

The digital twin may be generated by a decentral participant network node of a decentral network. The decentral participant node may be in communication with a decentral data providing network node providing access to the digital twin. The decentral participant node may be associated with a decentral data providing network node providing access to the digital twin. The digital twin may be generated by the data owner of the data associated with the product. The data owner of the data associated with the product may be the production producing the product. The data owner of the data associated with the

product may be the legal entity operating the production producing the product. The data owner of the data associated with the product may be the natural person operating the production producing the product. Te digital twin may be generated on behalf of the data owner of the data associated with the product. For instance, the digital twin may be generated by a third party based on a service provided by the third party to the data owner.

The digital twin may be generated by providing a digital twin template and applying aspect models defined in the digital twin template to gathered data associated with the product. The digital twin template may be provided by determining the appropriate digital twin template based on data associated with the product the digital twin is to be generated for. For instance, the product class associated with the product the digital twin is to be generated for may be used to determine the respective digital twin template. The data associated with the product may be gathered from one or more data sources based on data related to the product. The one or more data sources may be distributed data sources described previously. Data related to the product may include one or more product identifiers associated with the product. The one or more product identifiers may include a batch number, a product name, a product ID, a part number, a LOT number or a combination thereof. The product identifier(s) allow to uniquely identify the physical entity of the respective product, thus linking all data associated with said identifier(s) to the physical entity of the product. the data associated with the chemical product includes chemical product data. Data associated with the product may comprise data related to the use of the product, data related to the production of the product, one or more product identifiers, the product name, the product composition, measured and/or determined chemical and/or physical properties of the product, emission data of the product, recyclate content data of the product, bio-based content data of the product, renewable content data of the product, product declaration data, product safety data, certificate of analysis data associated with the product, certificates associated with the product, or a combination thereof.

The generated digital twin may be stored in a data storage. The data storage may be a database associated with the data owner. The data storage may serve as an intermediate layer between the data gathering and the consumption of the digital twin, for example by a decentral data consuming network node. The division between data gathering and consumption of the generated digital twin or associated digital twin data set(s) may result in a high and stable availability of digital twin data set(s) within a decentralized network can be achieved.

The generated digital twin or parts thereof (e.g. digital twin data set(s) contained in the digital twin) may be provided to a decentral data providing network node for access by a decentral data consuming network node. The decentral data consuming network node may be controlled or owned by or associated with a consumer of the product. The consumer may be any entity processing the product. The consumer may be any entity operating a production configured to the chemical product. The decentral data consuming network node may be controlled or owned by or associated with any upstream participant of the product ecosystem, including a product consumer, end-product manufacturer and participants of the recycling

chain associated with the product. Access to the digital twin or parts thereof may be controlled by the decentral data providing network node. The decentral data providing network node may be associated with the data owner of the digital twin data set(s). The decentral data providing network node may be associated with the data owner of the digital twin. Access to the digital twin or parts thereof may hence be under control of the data owner associated with the decentral data providing network node. This allows to retain full control over digital twin by the data owner but at the same time enabling sharing of the digital twin or parts thereof under controlled conditions, for example by using appropriate authorization and authentication mechanisms or schemes.

The digital twin generated using the digital twin template as generated by the apparatus or method disclosed herein may be associated with a digital access element. The digital access element may include a decentral access element identifier associated with the digital twin and access data. The digital access element may be used to access the associated digital twin or a part thereof.

The digital access element may represent a DID document associated with the decentral identifier, such as a Decentralized Identifier (DID). The DID document may be generated upon generation of the DID. The DID document may be generated after generation of the DID, for example upon generation of the digital twin. The DID document may contain the DID, further identifiers associated with the DID, such as digital twin data set identifiers, and access data. The access data may refer to any data for accessing the digital twin or parts thereof, such as digital twin data set(s) contained in the digital twin.

The decentral access element identifier may include one or more Universally Unique Identifier(s) (UUID(s)) or Digital Identifier(s) (DID(s)). The one or more DID(s) and/or UUID(s) may be associated with the digital twin as previously described.

Access data may include a digital representation pointing to at least one of the digital twin data sets associated with the digital twin. The access data may further include digital twin data set identifier(s) associated with digital twin data set(s) contained in the digital twin. The digital twin data set identifier may be one or more Universally Unique Identifier(s) (UUID(s)) or one or more Decentralized Identifier(s) (DID(s)). The digital twin data set identifier(s) may be requested from an ID generator prior to providing the generated digital twin to the decentral data providing network node. The digital twin data set identifier(s) may be retrieved from the digital twin. The digital twin data set identifier(s) may be retrieved from a digital access element, such as a DID document, generated upon generating the digital twin as described below. The digital representation may indirectly relate to a database storing the digital twin data set(s) and being associated with or accessible by the data owner associated with the digital twin data set(s). This may enhance security. The digital representation pointing to the at least one digital twin data set may include an endpoint for data exchange or sharing (resource endpoint) or an endpoint for service interaction (service Endpoint), that is uniquely identified via a communication protocol as previously described. The digital representation(s) pointing to the at least one digital twin data set may

hence be uniquely associated with the decentral identifier. The digital representation(s) pointing to the at least one digital twin data set may be regarded as locator(s) indication the location or dedicated data storage(s) where the respective digital twin data set is stored. Access data may include authorization schemes and/or cryptographic information. For instance, the access data may include a public key, such as a public key needed for decrypting the digital twin data set(s). Access data may include authentication schemes associated with the decentral identifier. The access data may be uniquely associated with the decentral digital twin identifier. The access data may be provided to the decentral data consuming network node. The access data may be provided by a decentral network database, a database associated with the decentral data consuming network node, the decentral data providing network node associated with the data owner or combinations thereof. Use of access data within the digital access element allows the data owner to retain the control over the digital twin because appropriate authorization and authentication is required to access the data contained in said digital twin. This allows to openly share the contents of the digital access element, for example on public web platforms, without having to disclose the digital twin or parts thereof associated with the digital access element via the decentral digital twin. Thus, transparency about existing digital access elements can be provided while at the same time ensuring the required level of confidentiality of the data contained in the digital twins associated with said digital access elements.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

In the following, the present disclosure is further described with reference to the enclosed figures. The same reference numbers in the drawings and this disclosure are intended to refer to the same or like elements, components, and/or parts.

FIG. 1A illustrates an example of a production controlled by an operating system comprising a digital twin management system.

FIG. 1B illustrates an example of a production controlled by an operating system to provide a product associated with a digital twin.

FIG. 1C illustrates another example of a production controlled by an operating system to provide a product associated with a digital twin.

FIG. 2 illustrates an example of a production system providing a product associated with a one or more digital twin(s).

FIG. 3A illustrates an example of a digital twin master template associated with a class of chemical products in accordance with an example embodiment of the present disclosure.

FIG. 3B illustrates an example of sub aspect models included in the composition aspect model of FIG. 3A in accordance with an example embodiment of the present disclosure.

FIG. 3C illustrates a first example of sub aspect models included in the compliance aspect model of FIG. 3A in accordance with an example embodiment of the present disclosure.

FIG. 3D illustrates a further example of sub aspect models included in the compliance aspect model of FIG. 3A in accordance with an example embodiment of the present disclosure.

FIG. 3E illustrates a further example of sub aspect models included in the compliance aspect model of FIG. 3A in accordance with an example embodiment of the present disclosure.

FIG. 4A illustrates an example of a digital twin template associated with a product generated by selecting aspect models included in a digital twin master template in accordance with an example embodiment of the present disclosure.

FIG. 4B illustrates an example of a digital twin template associated with a product generated by selecting aspect models included in a digital twin master template and further aspect models contained in a model database in accordance with an example embodiment of the present disclosure.

FIG. 5 illustrates an apparatus for generating a digital twin template associated with a product in accordance with an example embodiment of the present disclosure.

FIG. 6A, 6B illustrate a flow chart of a computer-implemented method for generating a digital twin template associated with a product or product class in accordance with an example embodiment of the present disclosure.

FIG. 7A illustrates an apparatus for generating a digital twin of a physical entity of a product using a digital twin template in accordance with an example embodiment of the present disclosure.

FIG. 7B illustrates a layered system for generating a digital twin of a physical entity of a product using a digital twin template in accordance with an example embodiment of the present disclosure.

FIG. 8 illustrates an example system and associated methods for generating a digital twin associated with a product produced by a chemical production and providing access to the generated digital twin.

FIG. 9 illustrates an example of generating a digital twin of a physical entity of a product using a digital twin template defining three models.

FIG. 10 illustrates a flow chart of a computer-implemented method for generating a digital twin of a physical entity of a product in accordance with an example embodiment of the present disclosure.

FIG. 11 illustrates a flow chart of a computer-implemented method for generating a digital access element associated with a digital twin of a product in accordance with an example embodiment of the present disclosure.

FIG. 12 illustrates an example of a system for providing a product produced by a production including an example method for generating a digital twin and a digital access element associated with the provided product.

FIG. 13 illustrates an example of a digital access element including DID owner data, DID document data and decentral identity infrastructure.

FIG. 14A illustrates a first example of a linkage between a digital twin, associated digital twin data sets and a digital access element via the decentral digital twin identifier.

FIG. 14B illustrates a second example of a linkage between a digital twin, associated digital twin data set and digital access elements via the decentral digital twin identifier.

FIG. 15 shows a schematic illustration of providing access via a decentral data providing network node associated with a data owner to a digital twin or a part thereof associated with a product using a decentral data consuming network node associated with data user.

DETAILED DESCRIPTION

The following embodiments are mere examples for implementing the method, the system or application device disclosed herein and shall not be considered limiting.

FIG. 1A illustrates an example of a production 104 producing one or more products(s) from one or more inbound material(s) 102 in connection with an operating system 108 including a digital twin management system. The operating system 108 may be used to operate the production 104, for example by managing different production chains present within the production 104. For producing one or more outbound product(s) 106, different materials 102 (also called inbound material 102 hereinafter) may be provided as physical inputs from material providers or suppliers. The physical inputs to the production 104 may include chemical materials, such raw materials, intermediate materials, chemical products, parts, assemblies or a combination thereof. Raw materials may be virgin or recycled raw materials. The inbound material 102 may be fed into the production 104 at any entry point. The inbound material 102 may be fed into the production 104 at the start of the production 104. The inbound materials may be considered input for the production 104.

The production 104 may be a chemical production. The chemical production may be a chemical production network including multiple interlinked processing steps. The chemical production network may be an integrated chemical production network with interrelated production chains. The chemical production network may include multiple different production chains that have at least one intermediate

product in common. The chemical production network may include multiple stages of the chemical value chain. The chemical production network may include multiple production chains that produce from one or more inbound material(s) as input chemical products as output. The chemical production network may include multiple tiers of a chemical value chain. The chemical production network may include a physically interconnected arrangement of production sites. The production sites may be at the same location or at different locations. In the latter case, the production sites may be interconnected by means of dedicated transportation systems such as pipelines, supply chain vehicles, like trucks, supply chain ships or other cargo transportation means.

The production 104 may include multiple production steps. The production steps included in the production 104 may be defined by the system boundary of the production 104. The system boundary may be defined by location or control over production processes. The system boundary may be defined by the site of the production 104. The system boundary may be defined by production processes controlled by one entity or multiple entities jointly. The system boundary may be defined by value chain with staggered production processes to an end product, which may be controlled by multiple entities separately.

The production 104 may convert inbound material 102 to at least one outbound product 106 that exits the production 104. The conversion may be performed by assembling inbound material 102, such as components or parts. The conversion may be a chemical reaction or any other processing step, such as physical processing. The conversion may be performed via intermediate chemical products. The chemical reaction may result in a mixture of different chemical product(s) since the yield of the chemical reaction may be less than 100%. Hence, a chemical reaction of one or more starting materials, such as inbound material(s) 202, may result in a mixture of different chemical product(s). Chemical reactions may therefore be characterized by a one-to-many or many-to-many relationship between starting materials and resulting reaction productions. This is in contrast to discrete manufacturing, where a many-to-one relationship between parts/components and assemblies is existing, e.g. the result of a discrete manufacturing step is a concrete and predictable assembly. Since the yield of a chemical reaction is not 100%, the amount of desired chemical product 106 (e.g. chemical product(s) to be supplied to upstream participants of the chemical ecosystem) is less than the theoretical amount of said chemical product calculated from the amount of starting materials. Such mixtures typically require separation of the different chemical products contained in said mixture. This allows to avoid a negative influence of impurities and unreacted inbound material(s) 102 on the further processing of the chemical product 106. Separation may include distillation, washing, extraction, crystallization and recrystallization. The resulting mixture may contain unreacted starting material, such as unreacted inbound material 102. Unreacted starting material may be reintroduced into the chemical reaction to reduce the amount of required starting material. The resulting mixture may contain desired chemical product(s) 106 to be supplied to upstream participants of the chemical ecosystem, such as chemical product consumers or chemical product processors. The resulting mixture may contain intermediate chemical product(s) used as input material in further chemical reactions performed within the chemical production. This allows to reduce the amount of waste associated with the

disposal of said intermediate chemical products and/or the amount of energy associated with transportation of these intermediate products to another chemical production. The resulting mixture may contain waste chemical product(s), e.g. chemical product(s) which cannot be used any further and which need to be disposed, for example by burning. Waste chemical products may be produced from undesired chemical side reactions.

The production 104 may comprise a plurality of sensors 110a, 110b. The sensors 110a, 110b may measure at least one chemical and/or physical property of the outbound product 106 produced by the production 104. The sensors 110a, 110b may measure at least one chemical and/or physical property of the inbound material 102 provided to the production 104. The sensors 110a, 110b may include sensors 110b configured to determine the amount of inbound material 102 and/or outbound product 106. Examples of such sensors may include scales or flow meters. The sensors 110a, 110b may include sensors 110a configured to measure at least one chemical and/or physical property of the inbound material 102. Measurement of chemical and/or physical properties of the inbound material 102 allows to control production processes based on the measured data. The sensors 110a, 110b may include sensors 110a configured to determine chemical and/or physical properties of the produced outbound product 106. Sensors 110a configured to measure chemical properties may measure data associated with or corresponding to the heat of combustion, enthalpy of formation, toxicity, chemical stability in a given environment, flammability, oxidation state(s), ability to corrode, combustibility, acidity and basicity and pH value. Sensors 110a configured to measure physical properties may measure data associated with or corresponding to absorption, brittleness, boiling point, capacitance, color, concentration, density, ductility, distribution, efficacy, elasticity, electric charge, electrical conductivity, electrical impedance, electric potential, flow rate, fluidity, hardness, heat capacity, inductance, intrinsic impedance, luminance, luminescence, luster, mass, melting point, opacity, permeability, permittivity, plasticity, pressure, radiance, resistivity, reflectivity, refractive index, solubility, specific heat, strength, stiffness, temperature, tension, thermal conductivity, thermal resistance, viscosity, volume and wave impedance. Data measured by sensors 110a, 110b may be stored in one or more databases, for example databases contained in data source layer 704 of FIG. 7A. The one or more databases may be distributed databases. The stored data may be interrelated with inbound material identifier(s) and/or product identifier(s), respectively.

The operating system 108 of the chemical production may monitor and/or control the production 104 based on operating parameters associated with the different processes performed by the production 104. One process step monitored and/or controlled may be the feed of inbound material 102 or the release of produced outbound product 106. Another process step monitored and/or controlled may be the separation of chemical product(s) contained in mixtures resulting from chemical reactions performed within the production 104 being a chemical production. Another process step monitored and/or controlled may be the determination of chemical and/or physical properties of produced outbound product 106 from data collected associated with the production of the chemical product, such as data measured by sensors 110a, 110b before, during and/or after production of the outbound product 106. Another process step

monitored and/or controlled may the generation of digital twin templates, for example as described in the context of FIG. 4A to FIG. 6A. Yet another process monitored and/or controlled may be the generation of digital twins, for example as described in the context of FIG. 7A to FIG. 10. Yet another process step monitored and/or controlled may be the access to generated digital twins by a decentral data consuming network node, for example as described in the context of FIG. 8. Yet another process step monitored and/or controlled may be the provisioning of products associated with digital twins, for example as described in the context of FIG. 8 and FIG. 15. Yet another process step monitored and/or controlled may be the generation of digital access elements associated with digital twins of produced chemical products, for example as described in the context of FIG. 11 and FIG. 12.

The operating system 108 may be configured to determine physical and/or chemical properties of the chemical product from collected data associated with the production of the chemical product. The operating system 108 may be configured to generate a digital twin template, for example as described in the context of FIG. 4A to FIG. 6A. The operating system 108 may be configured to update a digital twin master template, for example as described in FIG. 6B. The operating system 108 may be configured to generate a digital twin of a chemical product, for example as described in the context of FIG. 7A to FIG. 10. The operating system 108 may be configured to generate a digital access element, for example as described in the context of FIG. 11 and FIG. 12. The operating system 108 may be configured to control access to the generated digital twins by a decentral data consuming network node, for example as described in the context of FIG. 8 and FIG. 15.

FIG. 1B illustrates another example of a production 104 controlled by an operating system 108 to provide a product associated with a digital twin. The product may further be associated with a digital access element. The production 104 may be a chemical production producing chemical products 106 from at least one inbound material 102 as described in the context of FIG. 1A.

The process steps described in the context of FIG. 1A may be executed via operating system 108 of the production 104 in interaction with a requestor, an ID assignor, an apparatus for generating digital twin templates and an apparatus for generating digital twins 112. Operating system 108 may further be in interaction with an apparatus for generating digital access elements (not shown). In this embodiment, operating system 108 may be communicatively connected to the production 104 and may comprise the requestor, the ID assignor, the apparatus for generating digital twin templates and the apparatus for generating digital twins 112.

The apparatus for generating DT templates may be apparatus 500 described in the context of FIG. 5. The apparatus for generating digital twins may be the apparatus described in the context of FIG. 7A or the system described in the context of FIG. 7B.

The requestor may be configured to generate a request to generate the digital twin templates. The request may contain data related to the product, such as a product identifier and/or a product class. The product

identifier may include a batch number, a LOT number and/or a product ID. The request may be received at the digital twin template generator 504 (see for example FIG. 5) and the digital twin template generator 504 may, in response to the request, generate the digital twin template, for example using the method described in the context of FIG. 6A. The digital twin template generator 504 may further be configured to update the digital twin master template as described in the context of FIG. 6B.

The requestor may be configured to generate a request to generate the digital twins. The request may contain data related to the chemical product, such a batch number, LOT number and/or chemical product ID, and data related to at least one aspect model associated with chemical products as previously described. The request may be received at the data gathering unit 712 (see FIG. 7A) and the data gathering unit 712 may, in response to the request, initiate generation of the digital twin as described in the context of FIG. 7A and FIG. 10. The request may be received at the digital twin generator 716 (see FIG. 7A) and the digital twin generator 716 may, in response to the request, initiate generation of the digital twin as described in the context of FIG. 7A and FIG. 10. The requestor may further be configured to generate a request to generate a digital access element. The request may contain an owner identifier and/or a product identifier and/or access data as previously described.

The requestor may be configured to generate a request to generate a digital access element. The request may be received at the apparatus for generating the digital access element (see for example FIG. 12. The apparatus for generating the digital access element may be configured to generate a digital access element using the method described in the context of FIG. 11. An example of such a digital access element as generated by the apparatus is illustrated in FIG. 13.

The ID assignor may be configured to assign the decentral digital twin identifier included in the digital twin and/or the decentral access element identifier associated with the digital twin, and associated information to a physical identifier of the produced product as described in the context of FIG. 2. For instance, the ID assignor may generate a physical identifier having embedded the decentral digital twin identifier and/or the digital access element identifier and may provide the physical identifier to a labeling device.

The ID assignor, the requestor, the apparatus for generating digital twin templates, the apparatus for generating digital twins and/or the apparatus for generating digital access elements may be configured as decentral services or applications executed via a decentral network. The decentral network may be a decentral peer-to-peer communication network. The decentral network may include participant network nodes associated with participants of the product ecosystem and may be configured to perform data transactions, for example as described in the context of FIG. 15.

FIG. 1C illustrates yet another example of a production 104 controlled by operating system 108 to provide a product associated with a digital twin. The product may further be associated with a digital access

element. The production 104 may be a chemical production producing chemical products 106 from at least one inbound material 102 as described in the context of FIG. 1A.

The process steps described in the context of FIG. 1C may be executed via operating system 108 of the production 104 in interaction with a requestor, an ID assignor, an apparatus for generating DT templates, and an apparatus for generating digital twins of chemical products. The operating system 108 may further be in interaction with an apparatus for generating digital access elements (not shown). In this embodiment, operating system 108 may be communicatively connected to the production 104 and may comprise the requestor and the ID assignor 114. The operating system 108 may be communicatively connected to the apparatus for generating DT templates 116. The operating system 108 may be communicatively connected to the apparatus for generating digital twins 118.

The apparatus for generating DT templates 116 may correspond to apparatus 500 described in the context of FIG. 5. The apparatus for generating digital twins 118 may correspond to the apparatus described in the context of FIG. 7A or to the system described in the context of FIG. 7B.

The requestor may be configured to generate a request to generate the digital twin templates as described in the context of FIG. 1B. The requestor may be configured to generate a request to generate a digital twin as described in the context of FIG. 1C. The requestor may be configured to generate a request to generate a digital access element as described in the context of FIG. 1C.

The ID assignor may be configured to assign the decentral digital twin identifier and/or the decentral access element identifier and associated information to the physical identifier of the produced product as described in the context of FIG. 1C and FIG. 2. The requestor, the ID assignor, the apparatus for generating DT templates, the apparatus for generating digital twins of chemical products and/or the apparatus for generating digital access elements may be configured as decentral services or applications executed via a decentral network as described in the context of FIG. 1B.

FIG. 1B and FIG. 1C only show two example embodiments and any combination of the system components shown in FIG. 1B and FIG. 1C may be possible. For instance, the requestor may be configured as part of operating system 108, while the ID assignor may not be configured as part of operating system 108.

FIG. 2 illustrates an example of a production system providing products associated with digital twins. FIG. 2 specifically illustrates an example for generating a digital twin for a precursor material (e.g. intermediate chemical product) and for generating a digital twin for a chemical product produced at least in part from said precursor material. The chemical product, such as outbound product 106, may be produced by a chemical production, such as production 104, comprising an operating system 108, for example as described in the context of FIG. 1A to FIG. 1C.

The production of a chemical product may comprise a two-step process: 1) production of intermediate chemical product(s) from one or more inbound material(s), and 2) production of the chemical product at least in part from the intermediate chemical product(s). To produce the intermediate chemical product(s), inbound materials, such as inbound material 102, may be used as physical inputs. The inbound materials may be provided from raw material provider(s). The inbound materials may include virgin or recycled materials. The inbound materials may be provided to an intermediate chemical product production as inbound material 102. The intermediate chemical product production may be a chemical production as described in the context of FIG. 1A to FIG. 1C. The inbound materials may comprise a physical identifier. The physical identifier may be or may be associated with a decentral inbound material identifier. The decentral inbound material identifier may be associated with a digital twin of the inbound materials. The operating system, such as the operating system 108 described in the context of FIG. 1A to FIG. 1C, of the intermediate chemical product production may comprise or be in communication with an ID reader configured to read the physical identifier and to determine the decentral inbound material identifier associated with said physical identifier. The decentral inbound material identifier may be associated with a digital twin or a part thereof of the respective inbound material. The digital twin of the inbound materials may be generated using a digital twin template as described in the context of FIG. 7A to FIG. 10 below. The digital twin template may be generated as described in the context of FIG. 4A to FIG. 6A. The digital twin may include a measured physical and/or chemical property and/or a physical and/or chemical property determined from collected data associated with the production and/or the use of the inbound material. The physical and/or chemical property may be measured with sensors as described in the context of FIG. 1A to FIG. 1C. The physical and/or chemical property may be determined from collected data as described in the context of FIG. 1A to FIG. 1C. The digital twin may further include the inbound material name, inbound material producer, inbound material declaration data, inbound material safety data, emission data, recyclate content data, biobased content data, certificate of analysis data associated with the inbound material, certificates associated with the inbound material or a combination thereof.

The operating system may be configured to access the digital twin or a part thereof of inbound material(s) provided to the intermediate chemical product production based on the determined decentral inbound material identifier(s) e.g. from decentral data providing network node(s) associated with the inbound material provider(s) (see for example FIG. 15). Such data may be used to operate the chemical production producing the intermediate chemical product(s). For instance, if the inbound material(s) are recycled material(s), production steps purifying the recycled material(s) may be performed. For instance, if the inbound material(s) are virgin materials, purification steps may be omitted. The intermediate chemical product(s) may be formed by chemically reacting the inbound material(s) and/or by physically processing the inbound material(s). Chemical reactions may include polymerization, precipitation and other chemical reactions commonly known. Physical processing may include mixing, grinding, extruding, etc.. The intermediate chemical product production may include sensors, such as sensors 110a, 110b, measuring physical and/or chemical properties of the intermediate chemical product(s) produced by the intermediate

chemical product production as described in the context of FIG. 1A to FIG. 1C. The operating system may be configured to determine physical and/or chemical properties from collected data associated with the production of the intermediate chemical product(s), for example as described in the context of FIG. 1A to FIG. 1C.

The operating system may be configured to generate digital twin(s) for the produced intermediate chemical product(s) as described in the context of FIG. 4A to FIG. 10 below. Each digital twin may include a decentral intermediate chemical product identifier and at least one chemical and/or physical property of the respective intermediate chemical product measured by sensors 110a, 110b and/or at least one physical and/or chemical property of the respective intermediate chemical product determined from collected data. The digital twin may further include decentral inbound material identifier(s) of inbound material(s) used to produce the respective intermediate chemical product. This allows to track the inbound materials used to produce the respective intermediate chemical product. The digital twin may further include data previously described in relation with the digital twin of the inbound material(s). Intermediate chemical product digital access element(s) may be generated, for example as described in the context of FIG. 11 and FIG. 12. The produced intermediate chemical product(s) may be packaged, and the packaging may include a physical identifier, such as a QR code, an embossed code or an optical holographic code, such as zero-order diffractive microstructure. The physical identifier may be assigned to the respective decentral intermediate chemical product identifier of the digital twin and/or the respective decentral passport identifier of the intermediate chemical product digital access element. The assignment of the physical identifier and the decentral intermediate chemical product identifier may be executed through an ID assignor running locally, in a decentral system and/or in a distributed system. For instance, the packaging line may comprise a labelling device detecting the packaging of the produced intermediate chemical product(s). Based on such recognition, a requestor may generate a request to generate the digital twin and the respective decentral intermediate chemical product identifier included in the generated digital twin may be assigned, for example by the ID assignor, to the respective physical identifier (see also FIG. 8 below). Assigning may include encoding the respective decentral intermediate chemical product identifier in a physical identifier and providing the physical identifier, such as a code, to the labelling device configured to attach the physical identifier to the respective intermediate chemical product, such as the packaging of the respective intermediate chemical product. The ID assignor may be part of the labelling device or may be a separate device.

In a second step, the intermediate chemical product(s) produced in step 1) may be provided to a chemical production as inbound material 102 to produce the chemical product 106. The chemical production may be the production 104 described in the context of FIG. 1A to FIG. 1C. The chemical production may be the chemical production producing the intermediate chemical product(s). The chemical production may be different from the chemical production producing the intermediate chemical product(s). Apart from the intermediate chemical product(s) produced in step 1), further inbound material(s) may be provided to the chemical production and may be used to produce the chemical product 106. The intermediate chemical

product(s) may comprise recycled intermediate chemical product(s) and/or intermediate chemical product(s) produced by a different intermediate chemical product production than the intermediate chemical product production described in the context of step 1). Such intermediate chemical product(s) may be associated with a physical identifier. The physical identifier may be associated with a decentral intermediate chemical product identifier via which the digital twin or a part thereof of the respective intermediate chemical product may be accessible. An ID reader may be used to read the physical identifier associated with the respective decentral intermediate chemical product identifier as described above. The digital twin or a part thereof may be retrieved via a decentral data consuming network node using the decentral intermediate chemical product identifier as described above.

Production data from the intermediate chemical product production of the intermediate chemical product may be used by the operating system, such as operating system 108 described in the context of FIG. 1A to FIG. 1C, of the chemical production to produce the chemical product 106 as described above. The chemical production may include sensors, such as sensors 110a, 110b, measuring physical and/or chemical properties of the chemical product produced by the chemical production as described in the context of FIG. 1A to FIG. 1C. The operating system may be configured to determine physical and/or chemical properties from collected data associated with the production of the chemical product, for example as described in the context of FIG. 1A to FIG. 1C.

The operating system may be configured to generate a digital twin for the produced or packaged chemical product as described above. The digital twin may include a decentral chemical product identifier and at least one measured and/or determined physical and/or chemical property as outlined above. The digital twin may include decentral intermediate chemical product identifier(s). This allows to track the intermediate chemical product(s) used to produce the chemical product and also indirectly the inbound material(s) used to produce the intermediate chemical product(s). The digital twin may include further data as outlined above, such as the producer name, producer brand, producer identifier, chemical product name, chemical product brand and chemical product identifier.

A digital access element associated with the chemical product may be generated, for example as described in the context of FIG. 11 and FIG. 12. The decentral chemical product identifier and/or the digital access element may be associated with the chemical product via a physical identifier as described above. The digital access element may include a decentral access element identifier and access data. Access data may include a digital representation pointing to the digital twin or parts thereof. The decentral access element identifier may correspond to or be associated with the decentral chemical product identifier.

FIG. 3A illustrates an example of a digital twin master template associated with chemical products in accordance with an example embodiment of the present disclosure. While FIG. 3A illustrates an example of a digital twin master template for chemical products, this is not to be construed limiting and only serves

as an example. For instance, the digital twin master template may be associated with a product produced from such a chemical product, such as a component or part.

The digital twin master template may define a plurality of aspect models. The aspect model may define (i) the data structure of at least a part of a digital twin, such as the digital twin data set, resulting from application of the aspect model to product data associated with physical entity of the product or product class and (ii) one or more data points included in such part(s) of the digital twin. The data point(s) may define physical and/or chemical properties of the product or product class. The data point(s) may define data associated with the production of the product. The data point(s) may define data associated with the use of the product and/or the disposal or recycling of the product. The plurality of aspect models defined in the digital twin master template may include aspect models usable for any product or product class. For instance, the following aspect models may be usable for any product or product class: aspect model for template data (template meta data 306), aspect model for data of DT generated from master template (DT meta data 308) and aspect model for product producer (producer DM 310). The aspect model template meta data 306 may include the following attributes: identifier, version, creation data and time, issuer, comment on template. The aspect model DT meta data 308 may include the following attributes: identifier, version, date of last modification, data carrier ID number (e.g. ID of automatic identification data capture medium which may be read by a device), type of data carrier (e.g. data carriers according to ISO/EC 15459:2015), expiry date, layout (e,g, the layout in which the data carrier shall be presented and its positioning, correspond to product type (e.g. the product type, such as batch, the digital twin corresponds to), read accessibility data to actors (e.g. the participants of the decentral network that shall have access to the data in the digital twin and to what data they shall have access to), update accessibility data to actors (e.g. the participants of the decentral network that may update the data in the digital twin), accessibility data manner (e.g. the manner in which the digital twin may be made accessible to other participants of the decentral network), the author and unique ID of the digital twin creator (e.g. business partner number of the digital twin issuer). The aspect model producer DM 310 may be linked to a child aspect model defining the postal address of the producer (not shown) and may contain the following attributes: name, unique ID, supplier code, registered trade name, registered trademark, postal address, email address, telephone number, web address and EORI number.

The plurality of aspect models defined in the digital twin master template may include aspect models being specific for products or a product class. For instance aspect models for product identification (identification DM 312), product parameters (parameters DM 314), product safety data (safety data DM 316), product composition (composition DM 318), sustainability profile including emission data (sustainability DM 320), product waste management (waste management DM 322), product history (product history DM 324), product delivery (delivery DM 326), product packaging (packaging DM 328) and compliance data (compliance DM 330) may be specific for chemical products or a specific class of chemical products. The aspect model parameters DM 314 may contain the following attributes: net weight, physical state, color, odour, pH, melting point, freezing point, softening point, boiling point or

initial boiling point and boiling point range, flash point, flammability, lower explosion limit, upper explosion limit, auto ignition temperature, vapour pressure, decomposition temperature, kinematic viscosity, solubility, partitioning coefficient n-octanol water, relative density or density, relative vapour density, particle characteristics, flow time, other information (such as conductivity, burning rate, etc.), parameters after use (such as hardness, glossiness, scratch resistance, hiding power, metamerism etc.), dynamic parameters (e.g. product parameters acquired by sensors, such as temperature). The aspect model parameters DM 314 may define one or more sub aspect models (not shown). Examples of such sub aspect models include a test aspect model. The test aspect model may define data on the test methods used to determine the parameters defined in the parameter DM 314. Such data may include data on the test method used to determine the respective parameter. Data on the test method may include the name of the test method, parameter unit, short description of the performed test, test conditions, comments on the test method, result of the test method, executive summary of the test result, ID number of the test method, GLP compliance of the test method, or a combination thereof.

The compliance DM 330 may define one or more sub aspect model, such as illustrated in FIGs. 3C and 3E below. In addition to the sub aspect models illustrated in FIGs. 3C and 3E, further sub aspect models concerning certificate of analysis data may be defined. Such sub aspect models may define a link to the certificate of analysis data or structured certificate of analysis data or may be associated with open-source data structures for digital CoAs. The aspect model defining structured certificate of analysis data may include the following attributes: issuer, version, language, reference (e.g. sample description), customer (e.g. participant ordering the CoA), batch number, production data, shelf-life date and analysis list (e.g list of tests that are performed on sample), list of standards/certificates that laboratory performing tests comply with, remarks or a combination thereof. The aspect model defining the structured CoA data may define a test method aspect model. The test method aspect model may define the test method used to determine the product parameters contained in the CoA and may include the following attributes: test method (e.g. name of test method), ID of test method, unit of obtained value, short description of test method, conclusion of test method, executive summary of test, GLP compliance or a combination thereof. The aspect model defining the structured CoA data may define an aspect model defining upper and/or lower threshold values. The aspect model associated with open-source data structures for digital CoAs may use an open-source JSON data structure. The open-source JSON data structure may be available from www.materialidentity.org. The aspect model defining open-source data structures may contain the following attributes: format, format version (version identifier of format), URL to format definition file, payload (string with JSON according to open-source data structure).

The digital twin master template may include a plurality of aspect models and/or one or more digital representations pointing to the plurality of aspect models. The digital representation(s) may include an endpoint for data exchange or sharing (resource endpoint) or an endpoint for service interaction (service Endpoint), that is uniquely identified via a communication protocol. The digital representation(s) may be regarded as locator(s) indication the location or dedicated data storage(s) where the respective aspect

model is stored. Use of digital representation(s) within the digital twin master template allows to reduce the amount of data contained in said template to a minimum, allowing more efficient data transfer and maintenance of the digital twin master template.

The digital twin master template may define relationships between one or more aspect models of the plurality of aspect models defined in said master template. The relationships may define a tree structure for the plurality of aspect models defined in the digital twin master template, for example as shown in FIG. 3B to 3E. The tree structure may include one or more levels resulting in a hierarchical order of the aspect models defined in said digital twin master template. The relationship between aspect model(s) on a higher tree level with respect to aspect models in the following lower tree level may be described as a parent – child relationship, e.g. aspect models in the higher tree level may be denoted as parent aspect models while aspect models associated with said parent aspect models in the following lower tree level may be denoted as child aspect models. For instance, aspect model 304 may be denoted as parent aspect model (or root aspect model/root node) and aspect models 306 to 330 may be denoted as child aspect models of said parent aspect model 304.

The relationship(s) may be defined by relationship representation(s) specifying parent aspect model(s) associated with child aspect model(s) and/or child aspect model(s) associated with a respective parent aspect model. The relationship representation may be associated with the respective parent aspect model. The relationship representation may be associated with the respective child aspect models. The relationship representation may specify the relationship type between the respective parent aspect model child aspect models associated with the respective parent aspect model. For instance, the relationship representation associated with the root entity 304 (or root node) may specify the child aspect models 306 to 330 associated with said root entity and the relationship types between the root entity and each respective child aspect model. The relationship type may specify whether respective child aspect models may be mandatory aspect models or non-mandatory aspect models. Mandatory aspect models may be defined by a 1:1 or 1:many relationship type. In the embodiment of the master template shown in FIG. 3A, aspect models 306 to 318 and model DB 418 322 are defined by 1:1 relationship types with respect to root aspect model 304 and hence represent mandatory aspect models. Non-mandatory aspect models may be defined by a 1:0 or more relationship type. In the embodiment of the master template shown in FIG. 3A, aspect models 320, 324, 328 and 330 are defined by a 1:0 or 1:1 relationship type with respect to the root aspect model 304 and hence represent non-mandatory aspect models.

The relationship type may specify the number of child aspect models associated with the parent aspect model. For instance, a 1:1 relationship type may define that exactly one child aspect model, such as aspect model 306 is present with respect to root aspect model 304. In another instance, a 1:many relationship type (see for example FIG. 3B) may be used to define that more than one child aspect model may be associated with the respective parent aspect model.

Use of relationships between aspect models defined in the master template and hence a hierarchical structure of aspect models allows a flexible and modular approach to generate the digital twin template because aspect models not being suitable for the specific product or product class the digital twin template is to be generated for do not have to be selected and hence are not contained in the digital twin template. This avoids the presence of empty data fields due to the use of aspect models defining data types and attributes not available or applicable to the specific product or product class.

FIG. 3B illustrates an example of sub aspect models included in the composition aspect model 318 of FIG. 3A in accordance with an example embodiment of the present disclosure. Sub aspect models of the composition aspect model 318 may be referred to as child aspect models. The child aspect models may in turn define one or more sub aspect models.

In this embodiment, the composition aspect model 318 may be a child aspect model of root aspect model 304 and may have a 1:1 relationship to the root aspect model 304. Examples of attributes of composition aspect model 318 are listed in FIG. 3B. Each attribute may be associated with a defined data type as shown in FIG. 3B. The composition aspect model 318 may define sub aspect models. In this embodiment, the composition aspect model 318 defines a composition component aspect model (composition component DM 332). The composition component aspect model may have a 1:0 or 1:many relationship with the parent component aspect model 318. Hence, the composition component aspect models 332 may represent non-mandatory aspect models. Examples of attributes of composition component aspect model 332 are listed in FIG. 3B. Each attribute may be associated with a defined data type as shown in FIG. 3B.

This allows to consider the varying number of components present within different chemical composition. The composition component aspect models 332 may in turn be linked to identification aspect models 312. Identification aspect models 312 may contain the following attributes: specific code model number, unique ID, trade name, trade name code, index number, list number assigned by ECHA, authorization number, REACH number, Unique Formula Identifier (UIF) number, CAS number, EC number, other names of product in use (e.g. information about nanoform), TARIC code, commodity code, global trade identification number (e.g. as provided for in ISO/IEC 15459-6), classification code, EC name (e.g. name of component in the EC Inventory), IUPAC name, molecular formula. The composition component aspect models 332 may in turn be linked to nano particle characteristics aspect models (not shown). Such aspect models may define the characteristics of nano particles. Characteristics may include the chemical name, the particle size distribution D10, the particle size distribution D50, the particle size distribution D90, the crystallinity, the shape of the nano particles, the aspect ratio of the nano particles, the surface treatment of the nano particles, description of the surface treatment process, specific surface area of the nano particles, zeta potential of the nano particles, pour density of the nano particles, photocatalytic activity of the nano particles, radical formation potential of the nano particles, catalytic activity of the nano particles, porosity of the nano particles, dustiness of the nano particles, magnetic properties of the nano particles,

whether the nano particles meet the WHO fibre criteria, solubility of the nano particles, flammability and/or explosivity data of the nano particles, or a combination thereof. The aspect model defining the characteristics may be linked to a test aspect model as described in the context of FIG. 3A.

FIG. 3C illustrates a first example of sub aspect models included in the compliance aspect model 330 of FIG. 3A in accordance with an example embodiment of the present disclosure. Sub aspect models of the compliance aspect model 330 may be referred to as child aspect models.

In this embodiment, the compliance aspect model 330 may be a child aspect model of root aspect model 304 and may have a 1:0 or a 1:1 relationship to the root aspect model 304. Hence, the compliance aspect model 330 may be considered a non-mandatory aspect model. The compliance aspect model 330 may define sub aspect models. In this embodiment, three different sub aspect models 334, 336, 338 concerning the technical information associated with the product are illustrated. Defining different aspect models for the technical information on the product allows to select the appropriate aspect model upon generation of the digital twin template, hence ensuring that the available data on the produced product 106 can be appropriately mapped to the respective aspect model. This allows to standardize exchange of product data via digital twins since it ensures that data on technical information associated with the product is provided in a standardized way by selecting an appropriate aspect model. This modular approach hence provides a flexible way to generate digital twin templates defining appropriate aspect models, e.g. aspect models matching the available data on the produced product 106, thus allowing to generate digital twins for the produced products 106 comprising standardized data sets allowing standardized exchange of product data within the product ecosystem.

The technical info link aspect model 334 may have a 1:0 or 1:many relationship with the parent compliance aspect model 330. Hence, the technical info link aspect models 334 may represent a non-mandatory aspect model. Examples of attributes of technical info link aspect model 334 are listed in FIG. 3C. Each attribute may be associated with a defined data type as shown in FIG. 3C. This aspect model 334 allows referencing a technical information associated with the product via an URL, such as a publicly available URL. Utilizing this aspect model reduces the integration costs as the majority of technical information are already issued as PDF and made available through the internet.

The technical info binary aspect model 336 may have a 1:0 or 1:many relationship with the parent compliance aspect model 330. Hence, the technical info binary aspect models 336 may represent a non-mandatory aspect model. Examples of attributes of technical info binary aspect model 336are listed in FIG. 3C. Each attribute may be associated with a defined data type as shown in FIG. 3C. A base64 encoded technical information may be provided with aspect model 336. The binary file, such as a PDF file, may be encoded by the binary-to-text encoding “Base64” which is commonly used for data transfer within systems only supporting text characters. The data recipient may decode the textual information back into a binary file, such as a PDF file, which can be displayed via a viewer, such as a PDF viewer.

FIG. 3D illustrates an example of sub aspect models included in the safety data aspect model 316 of FIG. 3A in accordance with an example embodiment of the present disclosure. Sub aspect models of the safety data aspect model 316 may be referred to as child aspect models.

In this embodiment, the safety data aspect model 316 may be a child aspect model of root aspect model 304 and may have a 1:1 relationship to the root aspect model 304. Hence, the safety data aspect model 316 may be considered a mandatory aspect model. The safety data aspect model 316 may define sub aspect models. In this embodiment, the safety data aspect model 316 defines four different aspect models 340, 342, 344, 346 concerning safety data associated with the product. Safety data may include the at least one measured physical and/or chemical property mentioned with respect to FIG. 1A to FIG. 1C above. Defining different aspect models for the safety data associated with the product allows to select the appropriate aspect model upon generation of the digital twin template, hence ensuring that the available safety data on the produced product 106 can be appropriately mapped to the respective aspect model. This allows to standardize exchange of product data via digital twins since and hence provides a flexible way to generate digital twin templates defining appropriate aspect models, e.g. aspect models matching the available data on the produced product 106 as described in the context of FIG. 3C.

The safety info link aspect model 340 may have a 1:0 or 1:many relationship with the parent safety data aspect model 316. Hence, the safety info link aspect models 340 may represent a non-mandatory aspect model. Examples of attributes of safety info link aspect model 340 are listed in FIG. 3D. Each attribute may be associated with a defined data type as shown in FIG. 3D. This aspect model 340 allows referencing safety data associated with the product via an URL, such as a publicly available URL. Utilizing this aspect model reduces the integration costs as most safety data is already issued as PDF and made available through the internet.

The safety info binary aspect model 342 may have a 1:0 or 1:many relationship with the parent safety data aspect model 316. Hence, the safety info binary aspect model 342 may represent a non-mandatory aspect model. Examples of attributes of safety info binary aspect model 342 are listed in FIG. 3D. Each attribute may be associated with a defined data type as shown in FIG. 3D. A base64 encoded safety data may be provided with aspect model 336. The binary file, such as a PDF file, may be encoded by the binary-to-text encoding “Base64” which is commonly used for data transfer within systems only supporting text characters. The data recipient may decode the textual information back into a binary file, such as a PDF file, which can be displayed via a viewer, such as a PDF viewer.

FIG. 3E illustrates a further example of sub aspect models included in the compliance aspect model 330 of FIG. 3A in accordance with an example embodiment of the present disclosure. Sub aspect models of the compliance aspect model 330 may be referred to as child aspect models.

In this embodiment, the compliance aspect model 330 may be a child aspect model of root aspect model 304 and may have a 1:0 or a 1:1 relationship to the root aspect model 304 as described in the context of

FIG. 3C. The compliance aspect model 330 may define sub aspect models. In this embodiment, seven different sub aspect models 348, 350, 352, 354, 356, 370 and 372 are illustrated. Hence, compliance aspect model 330 may comprise the sub aspect models illustrated in FIG. 3C and/or the sub aspect models illustrated in FIG. 3E. All sub aspect models 348, 350, 352, 354, 356, 370 and 372 may have a 1:0 or 1:1 relationship with the parent compliance aspect model 330. Hence, all child aspect models 348, 350, 352, 354, 356, 370 and 372 illustrated in FIG. 3E may represent non-mandatory aspect models.

Child aspect model 348 may define data associated with the declaration of nano materials contained within the produced product 106. The declaration of nano materials may contain data indicating classification of a compound within the product being a nanomaterial according to existing regulations of the European Union, France, Belgium, Denmark, Sweden, Switzerland and the United States or according to existing definitions and vocabulary such as ISO TS 80004-1, recommendation of European Commission 2011/696/EU, etc.

Child aspect model supplier info 350 may contain information on the supplier of compounds present within the product 106. Attributes contained in said aspect model 350 may include the product name of the supplied compound, country of origin of the supplied compound, supplier name, supplier identifier, manufacturer, composition of the supplied compound and chemical registration data of the supplied compound. Supplier info aspect model 350 may be linked to further child models, such as composition component aspect model 358, chemical registration aspect model 360, signature area aspect model 362 and customs aspect model (not shown, may define customs tariff number of supplied product). The relationship may vary from one aspect model to another. For instance, aspect model 358 may have a 1:0 or 1:many relationship with parent aspect model 350 to reflect more than one compound being contained within the product while aspect models 360 and 362 as well as the customs aspect model (not shown) may have a 1:1 relationship with parent aspect model 350.

Composition component aspect model 358 may contain the following attributes: CAS number, content, name or an encoded document as described in the context of FIG. 3C. Signature area aspect model 362 may contain the following attributes: data indicating that information is true and complete, comments, company name, function, name, date, phone number, email address and signature information.

Chemical registration aspect model 360 may be a parent aspect model for aspect models 364, 366 associated with the registration of the supplied material 102 in various countries. The number of aspect models 364, 366 may vary and may depend on the number of countries where chemical compounds need to be registered. Countries where chemical compounds need to be registered may include Australia, Canada, China, Japan, Korea, New Zealand, Philippines, Switzerland, Taiwan and USA. Registration info EUREACH aspect model 368 may contain data concerning registration of all compounds according to REACH.

Trade control DM 352 may include the following attributes: product name, name of supplied product, ID of supplier (such as a unique participant identifier used within the decentral network), supplier contact. Trade control DM 352 may define one or more sub aspect models. The relationship between trade control DM 352 and the one or more sub aspect models may be a 1:1 relationship. The sub aspect models may include a signature area aspect model, such as signature area DM 362, an aspect model for global trade control defining whether the product contains any compound(s) listed as chemical and/or biological weapon, and/or one or more aspect models for specific regions specifying regulations concerning the declaration of compounds.

Reach DM 354 may include the following attributes: product name, name of product supplier, ID of product supplier (such as a unique participant identifier used within the decentral network), country code of product origin or a combination thereof. Reach DM 354 may define one or more sub aspect models. The relationship between trade control DM 352 and the one or more sub aspect models may be a 1:1 relationship. The sub aspect models may include a signature area aspect model, such as signature area DM 362, and an aspect model defining Reach information for a region, such as EMEA.

SPM info DM 370 may define information on synthetic polymer microparticles (SPMs). Synthetic polymer microparticles may be synthetic polymer microparticles defined according to Regulation (EC) No 1907/2006 REACH Annex XVII. For instance, synthetic polymer microparticles (SPM) may be polymers that are solid and which (a) are contained in particles and constitute at least 1 % by weight of those particles; or build a continuous surface coating on particles and (b) at least 1 % by weight of the particles referred to in point (a) fulfil either of the following conditions: (b.i) all dimensions of the particles are equal to or less than 5 mm; (b.ii) the length of the particles is equal to or less than 15 mm and their length to diameter ratio is greater than 3 and (c) are not polymers that are the result of a polymerization process that has taken place in nature which are not chemically modified substances; and (d) are not polymers that are degradable as proved in accordance with Appendix [X]; and (e) are polymers which do not have a solubility greater than 2 g/L as proved in accordance with Appendix [Y]; and (f) are polymers which contain carbon atoms in their chemical structure. The synthetic polymer microparticles aspect model may contain the following attributes: product includes SPM, list of SPM. Product includes SPM may be a Boolean defining whether synthetic polymer microparticles are present in concentration of equal or higher than 0,01% by weight. The synthetic polymer microparticles aspect model may define one or more sub aspect models, such as SPM item DM 374. The relationship between the synthetic polymer microparticles aspect model and the one or more sub aspect models may be a 1:0 or 1:many relationship. The one or more sub aspect models may define a list of SPMs present within the chemical material. The list of SPMs may contain data on the identity of the SPM, such as a CAS number, data on the quantity or concentration of the SPM in the chemical material, and/or data on the function and/or sought-after characteristic of the SPM.

GxP DM 372 may define documentation required in regulated environments. The regulated environments may specify guidelines to assure a high product quality and may include defined documentation requirements. Part of the required documentation may be shared with further participants of the decentral participant network. The required documentation may be shared in case of an audit. Examples of such regulated environments include good manufacturing practice (GMP), good laboratory practice (GLP), good clinical practice (GCP) and ISO certifications, such as ISO 17025. The regulated environment aspect model may define a list of qualified electronic signatures. The regulated environment aspect model may define one or more sub aspect models. The relationship between regulated environment aspect model and the one or more sub aspect models may be a 1:0 or 1:many relationship. The one or more sub aspect models may include an aspect model specifying required documentation (such as storage location of site master file, data on risk management, data on quality assurance system and data on the confirmation according to Article 46b(2)(b) of Directive 2001/83/EC), an aspect model specifying required reports (such as CoA) and/or an aspect model specifying data on the electronic signature.

The compliance aspect model 330 may contain further sub aspect models not illustrated in FIG. 3C and FIG. 3E. Such further aspect models may include a UKREACH info aspect model and a KKDIK info aspect model.

The compliance aspect model 330 allows to compile data that contains all information required by a receiver of the material 102 to fulfill regulatory requirements. For instance, the compliance aspect model 330 allows to compile required data from a supplier in a standardized format, allowing to simply the data acquisition and exchange process between a supplier of a material 102 and a producer of a product 106 from said material. The supplier of the material 102 may use the compliance aspect model 330 and appropriate sub aspect models to generate a digital twin template that allows to generate a digital twin of the material containing all data required by the material consumer (e.g. operator of production 104). The data obtained in a standardized format from the supplier can be used during generation of digital twins of products 106 produced from said material 102.

FIG. 4A illustrates an example of a digital twin template associated with a product generated by selecting aspect models included in a digital twin master template in accordance with an example embodiment of the present disclosure. The product may be produced by a production, such as production 104 described in the context of FIG. 1A to FIG. 1C from at least one inbound material 102.The product may be a chemical product.

The digital twin master template may define a plurality of aspect models 402, 404, 406, 408. The digital twin master template 302 may be the digital twin master template 302 described in the context of FIG. 3A to FIG. 3E. The plurality of aspect models may include mandatory aspect models, such as aspect models 402, 404, and non-mandatory aspect models, such as aspect models 406, 408, as described in

the context of FIG. 3A to FIG. 3E. At least a part of the aspect models included in the digital twin master template 302 may define chemical and/or physical properties of the product or the product class.

Generation of the digital twin template 410 from the digital twin master template 302 may include selection of at least one aspect model from the plurality of aspect models defined in the master template 302. The digital twin template 410 may be generated using the apparatus disclosed in the context of FIG. 5. The digital twin template 410 may be generated according to the method described in the context of FIG. 6A. In this embodiment, two mandatory aspect models 402, 404 and non-mandatory aspect model 406 have been selected to generate digital twin template 410. Selection of the aspect models defined in the digital twin master template 302 may be performed as described in the context of FIG. 6A. The digital twin template 410 may define or include the selected aspect models. The digital twin template 410 may define or include digital representations pointing to at least part of the selected aspect models. This allows to update generated digital twin templates 410 more efficiently because it avoids updating of the digital twin template 410 as such. Instead, it is sufficient to update the respective aspect model since the digital representation will point to the updated aspect model without having to amend the digital twin template as such.

FIG. 4B illustrates an example of a digital twin template associated with a product generated by selecting aspect models included in a digital twin master template and further aspect models contained in a model database in accordance with an example embodiment of the present disclosure. The product may be produced by a production, such as production 104 described in the context of FIG. 1A to FIG. 1C from at least one inbound material 102.The product may be a chemical product.

The digital twin master template 302 may define a plurality of aspect models 402, 404, 406, 408 as described in the context of FIG. 4A. The model database 418 may include at least one further aspect model 412, 414, 416. The at least one further aspect model may be different from the aspect models 402 to 408 defined in the digital twin master template 302. The at least one further aspect model may define a tree structure with one or more levels, for example as described in the context of FIG. 3B to FIG. 3E. Hence, the at least one further aspect model may define one or more child aspect models which in turn may define further child models and so on. The further aspect models may be specific for the product the DT template 420 is generated for. The model DB 418 may be part of a decentral network as described previously.

Generation of the digital twin template 420 from the digital twin master template 302 may include selection of at least one aspect model from the plurality of aspect models defined in the master template 302 as well as selection of at least one further aspect model stored in model DB 418. The digital twin template 420 may be generated using the apparatus disclosed in the context of FIG. 5. The digital twin template 420 may be generated according to the method described in the context of FIG. 6A. In this embodiment, two mandatory aspect models 402, 404 and non-mandatory aspect model 406 have been selected from

the digital twin master template DT master template(s) for products 302 and two further aspect models 414, 416 have been selected from model DB 418 to generate digital twin template 420. In this embodiment, 2 further aspect models have been selected. However, it is also possible to select less or more further aspect models. Selection of the aspect models defined in the digital twin master template 302 and the model DB 418 may be performed as described in the context of FIG. 6A. The digital twin template 420 may define or include digital representations pointing to at least part of the selected aspect models as described in the context of FIG. 4A.

The selected further aspect models 414, 416 may be used to update digital twin master template 302 by amending said master template 302 such that further aspect models 414, 416 are defined therein (not shown). The master template 302 may be updated as described in the context of FIG. 6B. Updating the digital twin master template 302 allows to provide a broader selection of aspect models to other participants of the ecosystem generating digital twins, reducing the effort necessary to generate product specific aspect models and ensuring the required standardization to allow simplified and customized exchange of product data within the product ecosystem.

FIG. 5 illustrates an apparatus 116 for generating a digital twin template associated with a product in accordance with an example embodiment of the present disclosure. The product may be a chemical product. Apparatus 116 may be a decentral participant node of a decentral network. Apparatus 116 may be included in the operating system 108 of a production 104 producing products 106 from one or more inbound materials 102 (see for example FIG. 1A to FIG. 1C). The production 104 may be a chemical production, for example as described in the context of FIG. 1A and FIG. 2. Apparatus 116 may be communicatively coupled to the operating system 108 of a production 104 producing products 106 (see FIG. 1C). Apparatus 116 may be configured to generate a digital twin template associated with a product, for example using the method described in the context of FIG. 6A. Apparatus 116 may be configured to update a digital twin master template, for example as described in the context of FIG. 6B.

Apparatus 116 may be connected to a decentral network 514. The decentral network may be a decentral peer-to-peer communication network. The decentral network may include participant network nodes associated with participants of the product ecosystem. The decentral participant node may comprise a network node of the decentral network. The decentral participant node may be connected to or may be included in the apparatus for generating DT templates 116. The apparatus for generating DT templates may comprise a decentral data consuming network node (not shown, see for example FIG. 15) configured to consume master template(s) 302 from the master template DB 512. The decentral network 514 may include infrastructure nodes. The infrastructure nodes may not be associated with participants of the product ecosystem. The infrastructure node may comprise network nodes of the decentral network 514. The infrastructure nodes may comprise master template DB 512. The infrastructure nodes may comprise model DB 418.

The decentral network 514 may be configured to perform data transactions. The data transactions may be based on a transaction protocol including authentication and/or authorization mechanism(s). Based on the authentication and/or authorization mechanism(s) a peer-to-peer communication between decentral network nodes associated with participants of the product ecosystem may be established. The one or more authentication mechanism(s) may be associated with or linked to the decentral digital twin identifier and/or the decentral access element identifier. The one or more authentication mechanism(s) may be associated with or linked to decentral participant identifier(s) associated with participants of the product ecosystem.

Master template DB 512 may store at least one digital twin master template 302. An example of a digital twin master template stored in master template DB 512 is illustrated in FIG. 3A to Fig. 3F. The digital twin master template 302 stored in master template DB 512 may define a plurality of aspect models as described in the context of FIG. 3A to Fig. 3F. The master template DB 512 may be connected to a decentral data providing network node (not shown) configured to control access to master template(s) 302. Master template DB 512 may be configured to provide a master template 302.

Model DB 418 may store at least one further aspect model as described in the context of FIG. 4B. The model DB 418 may be connected to a decentral data providing network node (not shown) configured to control access to model DB 418. Model DB 418 may be configured to provide at least one further aspect model.

Apparatus for generating DT templates 116 may comprise a digital twin template generator 504. Digital twin template generator 504 may be configured to receive a request to generate the digital twin template. The request may be received from a user via an I/O device 510. The I/O device 510 may be connected to digital twin template generator 504 via a communication interface, such as a network. The I/O device 510 may be configured to display a user interface allowing the user to select a master template 302 and/or one or more further aspect models. The user interface may display available master template 302 stored in master template DB 512 and/or available further aspect models stored in model DB 418. Data on available master templates 302 and/or further aspect models may be gathered via decentral data consuming network node associated with digital twin template generator 504 and may be provided to I/O device 510 for display on the screen.

The request may include data related to the product. Data related to the product may include a product identifier and/or a product class as described in the context of FIG. 6A. Digital twin template generator 504 may be configured to gather a digital twin master template associated with one or more product classes. The master template 302 may be gathered from master template DB 512. The master template 302 may be gathered based on data contained in the received request. Gathering the master template 302 may include retrieving or receiving said master template 302 from master template DB 512.

Digital twin template generator 504 may be configured to gather product data based on the data contained in the received request. Gathering may include retrieving or receiving product data. Product data may be stored in product data DB 502. Product data may include data or classes of data to be included in a digital twin associated with the product. Classes of data may include data related to the use of the product, data related to the production of the product, product composition data, product property data, data associated with the ecological profile of the product, regulatory data associated with the product, certificates associated with the product, or a combination thereof. The product data may further include one or more product identifiers and/or the product name. The at least one product identifier may correspond to the product identifier(s) contained in the received request. Product data DB 502 may be associated with a production, such as production 104 described in the context of FIG. 1A to FIG. 2, producing the product 106 from one or more materials 102 entering the production. The product data DB 502 may be distributed data sources as previously described.

Digital twin template generator 504 may be configured to gather one or more further aspect models. Gathering may include retrieving and/or receiving the at least one further aspect model. The further aspect models may be gathered from model DB 418. The further aspect models may be gathered based on data contained in the received request. The further aspect models may be gathered based on gathered product data.

Digital twin template generator 504 may be configured to generate - based on the gathered product data - the digital twin template. The digital twin template may define at least one aspect model defined in the digital twin master template. The digital twin template may further define at least one further aspect model stored in model DB 418. Generating the digital twin template may including selecting at least one aspect model defined in the master template 302, for example as described in the context of FIG. 4A and FIG. 6A. Generating the digital twin template may include selecting at least one aspect model defined in the master template 302 and at least one further aspect model, for example as described in the context of FIG. 4B and FIG. 6A. Selecting at least one aspect model may include matching the gathered product data to chemical and/or physical properties defined by the respective aspect models (e.g. aspect models included in the digital twin master template 302 and optionally further aspect models). Generated digital twin templates may be provided to template DB 506. Template DB 506 may store generated digital twin templates. The stored digital twin templates may be interrelated with a product identifier or a product class identifier. This allows to gather the digital twin template, for example upon generation of the digital twin of the product. The digital twin template may be generated for a specific product. The digital twin template may be generated for a product class.

FIG. 6A and FIG. 6B illustrate an example of a computer-implemented method for generating a digital twin template associated with a product or product class in accordance with an example embodiment of the present disclosure. The product may be a chemical product. The product may be produced by production 104 from at least one inbound material 102 (see FIG. 1A to FIG. 2). Production 104 may be a

chemical production (see FIG. 2). The method may be implemented using apparatus 116 described in the context of FIG. 5. The digital twin template may be generated by operating system 108 of production 104. Operating system 108 may comprise an apparatus for generating DT templates 116 as described in the context of FIG. 5. The request to generate the digital twin may be triggered manually by a user via a user interface, for example using I/O device 510 (see FIG. 5). The digital twin template may define one or more aspect models contained in a digital twin master template used to generate the digital twin template (see FIG. 4A). The digital twin template may further define one or more further aspect model(s), such as further aspect model(s) provided from model DB 418 (see FIG. 4B).

In block 608, a request to generate the digital twin template may be received. The request may contain data related to the product. Data related to the product may include a product identifier, a product class or a combination thereof. The product identifier may include a batch number, a product name, a product ID, a part number, a LOT number or a combination thereof. The LOT number may be assigned to the product on production.

In block 610, a digital twin master template may be provided. The digital twin master template may define a plurality of aspect models. At least a part of the aspect models may describe chemical and/or physical properties of the product or product class, for example as illustrated in FIG. 3A. The plurality of aspect models may be defined by the digital twin master template by including such aspect models in the digital twin master template (see for example FIG. 3A). The plurality of aspect models may be defined by the digital twin master template by including one or more digital representations pointing to such aspect models in said digital twin master template. An example of a digital master template and aspect models defined by such digital twin master template provided in block 604 are described in the context of FIG. 3A to FIG. 3E. The digital twin master template may be provided from a data storage 604 comprising at least one digital twin master templates. Data storage 604 may be a central database. Data storage 604 may be part of a decentral network, such as decentral network 514. The digital twin master templates stored in the data storage 604 may be accessed by a decentral data consuming network node, such as decentral data consuming network node 808. The decentral data consuming network node may be part of the decentral network 514. The decentral data consuming network node may be associated with the participant of the product ecosystem generating the digital twin template. The stored digital twin master template may be provided by a decentral data providing network node associated with data storage 604. The decentral data providing network node may be part of the decentral network 514. The decentral configuration allows for more efficient use of computing resources.

In block 612, product data may be provided based on data related to the product contained in the received request. Product data may include data or classes of data to be included in a digital twin associated with the product. Classes of data may include data related to the use of the product, data related to the production of the product, product composition data, product property data, data associated with the ecological profile of the product, regulatory data associated with the product, certificates associated with

the product, or a combination thereof, as previously described. The product data may further include one or more product identifiers and/or the product name. The at least one product identifier may correspond to the product identifier(s) contained in the received request. Product data may be provided from data storage 602 storing said product data. Product data may be provided based on product identifier(s) contained in the received request. Data storage 602 may correspond to data source layer 704 described in the context of FIG. 7A. Data storage 602 may correspond to DT storage 720 storing gathered data associated with the product as described in the context of FIG. 7A.

In decision block 614, it may be determined whether further aspect model(s) are to be provided. The decision may be based on the provided product data. For instance, the provided product data may be used to determine further aspect model(s) matching said product data or a part thereof. Matching further aspect models may be determined by matching the product data with data point(s) defined by the further aspect models, such as chemical and/or physical properties defined by such aspect models. If it is determined in block 614 that further aspect model(s) are to be provided, the method may proceed to block 620. Otherwise, the method may proceed to block 616.

In block 616, the digital twin template may be generated by selecting at least one aspect model from the plurality of aspect models defined in the provided digital twin master template based on the provided product data. Selecting at least one aspect model from the plurality of aspect models defined in the digital twin master template may include mapping the provided product data to aspect model(s) defined in the digital twin master template. The mapping may include matching the provided product data to aspect model data associated with the aspect models defined in the digital twin master template. The mapping may include matching the provided product data to data point(s) chemical and/or physical properties defined by the aspect models included in the digital twin master template. In case the provided product data may map on one or more aspect model(s) defined in the digital twin, said aspect model(s) may be selected. In addition, aspect model(s) may be selected from the plurality of aspect models defined in the digital twin master template based on relationships between one or more aspect models of the plurality of aspect models. For instance, the relationships may define mandatory aspect model(s) which may be selected based on such relationships.

In block 618, at least one further aspect model may be provided. The at least one further aspect model may be provided from a storage environment 606, such as model DB 418 described in the context of FIG. 4B and FIG. 5, comprising further aspect model(s). Storage environment 606 may be a central database. Storage environment 606 may be part of a decentral network, such as decentral network 514. The further aspect model(s) stored in storage environment 606 may be accessed by a decentral data consuming network node as previously described. The decentral data consuming network node may be associated with the participant of the product ecosystem generating the digital twin template. The stored further aspect model(s) may be provided by a decentral data providing network node associated with the database as previously described. Use of further aspect model(s) not defined in the digital twin master

template allows to generate digital twin templates for products in a flexible way such that the digital twin of the product generated using said digital twin templates contains all required data. Hence, available aspect model(s) (e.g. aspect models defined in the digital twin master template and further aspect models) may be combined in a modular approach to design a digital twin template for a specific product or product class which allows to generate digital twins for such product or product class containing all data required to fulfill at least the regulatory requirements associated with such product or product class. The modular approach further allows to consider requirements imposed by downstream participants of the product value chain, such as consumers of the product and further downstream participants, and/or well as participants of a recycling chain associated with the product. This allows to ensure that the digital twin template contains all aspect models which are necessary to fulfill not only the regulatory requirements but also further requirements imposed by participants of the product ecosystem.

In block 622, the digital twin template may be generated by selecting at least one aspect model from the plurality of aspect models defined in the provided digital twin master template and by selecting at least one further aspect model. Selecting at least one aspect model from the plurality of aspect models defined in the digital twin master template may include mapping the provided product data to the further aspect model(s) as described previously (see block 616). Selecting at least one further aspect model from the provided further aspect models may include mapping the provided product data to the further aspect model(s) as described in the context of block 616.

The digital twin template generated in block 616 or block 622 may include at least one of the aspect models defined in the digital twin master template (see also FIG. 4A). The digital twin template generated in block 620 may include at least one of the aspect models defined in the digital twin master template and at least one further aspect model (see also FIG. 4B). The digital twin master template generated in block 616 or block 622 may include one or more digital representations pointing to aspect model(s) defined in the digital twin master template. The digital twin template generated in block 622 may include one or more digital representations pointing to the further aspect models selected in block 622. The digital twin template may hence contain a subset of the aspect models defined in the digital twin master template. The digital twin template may contain additional aspect model(s) not defined in the digital twin master template. This allows to generate a digital twin template containing all aspect models which are necessary to fulfill the regulatory requirements as well as requirements imposed by participants of the product ecosystem.

In block 618, the digital twin template generated in block 616 may be provided. Providing the generated digital twin template may include providing said digital twin template to a database, such as template DB 506 described in the context of FIG. 5. The digital twin template may be interrelated with data associated with the product and/or with product data in said database. For instance, the digital twin template may be interrelated with one or more identifier(s) associated with the product or the product class in said database. Providing the digital twin template may include providing said template via a communication

interface for display. This allows to control the aspect models defined in said template to ensure that all required aspect models are defined properly. This avoids missing data in the digital twin generated from said digital twin template and hence ensures that digital twins generated from said digital twin template contain all required data.

In block 624, the digital twin template generated in block 622 may be provided as described in the context of block 618.

The method illustrated in FIG. 6A allows to generate customized digital twin templates using a modular approach by selecting one or more aspect models from a digital twin master template defining a plurality of aspect models existing for products or product classes in a hierarchical order. Generation of the digital twin template may further include selection of further aspect models not contained within the digital twin master template, allowing to consider product peculiarities not embraced by the aspect models included in the digital twin master template. This modular approach allows to select appropriate aspect models, e.g. aspect models required to describe properties of the product to fulfill regulatory requirements for produced products, from the digital twin master template and optionally further available aspect models, hence ensuring that the digital twins of products generated from such customized digital twin templates have a highly defined data structure simplifying data exchange and sharing while at the same time containing all relevant data required to meet the regulatory requirements. This modular approach significantly reduces the complexity associated with the generation of one single aspect model for each product or product class and allows to efficiently generate digital twin templates for a variety of different products or product classes. Moreover, the modular approach avoids issues regarding maintenance of a single large aspect model and the use of inappropriate semantic descriptions for a specific product or product class within such a single large aspect model, hence avoiding empty attributes due to missing product data in the digital twin.

In decision block 626, it may be determined whether the digital twin master template is to be updated. The decision may be based on whether at least one further aspect model was used to generate the digital twin template (e.g. if blocks 620 and 622 are performed). If the generated digital twin master template is not to be updated, the method may end or return to block 608. If the generated digital twin is to be updated, the method may proceed to block 628.

In block 628, the provided digital twin master template may be updated with at least one further aspect model provided in block 620. Updating may include defining the one or more further aspect model(s) in the digital twin master template. Defining the one or more further aspect models may comprise including said further aspect model(s) in the digital twin master template. Defining the one or more further aspect model(s) may include defining digital representations pointing to said further aspect model(s) in the digital twin master template.

In decision block 630, it may be determined whether the updated digital twin master template may be provided. If the updated digital twin master template is to be provided, the method may proceed to block 632. Otherwise, the method may end or return to block 608.

In decision block 630, the updated digital twin master template may be provided to a database, such as template DB 506 and/or master template DB 512 described in the context of FIG. 5. After block 630, the method may end or may return to block 608.

Updating the digital twin master template with further aspect models allows to increase that number of aspect models available to generate digital twin templates and to share aspect models generated for a specific product or product class with other participants of the product ecosystem. This may result in more efficient generation of digital twin templates due to the increased number of available aspect models that can be used for the modular approach during the generation of the digital twin template.

FIG. 7A illustrates an example apparatus 702 for generating a digital twin of a physical entity of a product using a generated digital twin template. . The digital twin template may be generated by apparatus for generating DT templates 116 described int the context of FIG. 5. The digital twin template may be generated according to the method described in the context of FIG. 6A and FIG. 6B. The product may be a chemical product. Apparatus 702 may be a decentral participant node of a decentral network. Apparatus 702 may be included in operating system 108 of a production 104 producing products 106 from one or more inbound materials 102 (see for example FIG. 1A and FIG. 1B). Apparatus 702 may be communicatively coupled to operating system 108 of a production 104 producing products 106 (see FIG. 1C). The apparatus 702 may be configured to generate a digital twin of a chemical product, for example using the method described in the context of FIG. 10.

Apparatus 702 may be coupled to data source layer 704 comprising one or more distributed data sources 706, 708, 710. Apparatus 702 may comprise the data source layer 704 (not shown). The one or more distributed data sources may be distributed databases. The distributed data source may be a data lake comprising data associated with products from a plurality of distributed data sources. In this example, the data source layer 704 contains three distributed data sources. However, the data source layer 704 may also comprise less or more distributed data sources. The one or more distributed data sources may contain data associated with products, such as chemical products produced by chemical production 104 from one or more inbound materials 102 as described in the context of FIG. 1A to FIG. 2. The data associated with products may include at least one measured physical and/or chemical property of each product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of each product. The at least one physical and/or chemical property may be measured using sensors, such as sensors 110a, 110b, and the measured and/or physical property/properties may be stored in the distributed data sources. The at least one physical and/or chemical property may be determined from data acquired from sensors, such as sensors 110a, 110b,

before, during and/or after production and the determined chemical and/or physical property/properties may be stored in the distributed data sources. The one or more distributed data sources may further contain product names, product producer, product declaration data, product safety data, emission data, recyclate content data, biobased content data, certificate of analysis data associated with the products, certificates associated with the products or a combination thereof.

The data associated with products may be acquired before, during and/or after production of the products 106. The acquired data may be provided to the data source layer 704 for storage. The data source layer 704 may be owned or controlled by the data owner of the data associated with the product data. The data source layer 704 may be associated with the data owner of the data associated with the product data. At least one of the distributed data sources may contain data instances that relate to the product 106 for which apparatus 702 is configured to generate the digital twin. At least one data instance may contain at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product. The data source layer 704 may be connected, for example via a communication interface such as a network or an API, to a data gathering unit 712. The data source layer 704 may be connected directly to the data gathering unit 712 or may be connected to a further layer being present in between the data source layer 704 and the data gathering unit 712 (not shown, see for example FIG. 7B).

Data gathering unit 712 may be configured to receive a request to generate a digital twin associated with a product 106 produced by production 104. The request may contain data related to the product. Data related to the product may include product identifier(s) associated with the produced product 106, such as a batch number, a LOT number, an ID, or a combination thereof. Data gathering unit 712 may be configured to gather data associated with the product from the data source layer 704 based on the received data related to the product. For instance, a product identifier may be received with the request, such as a batch number, and said received product identifier may be used to gather data associated with said product identifier. In another instance, the product identifier may be received from a user via an I/O device 510.

Data gathering unit 712 may be configured to determine, upon receiving the request to generate the digital twin, whether a digital twin associated with said product is already contained in DT storage 720. For instance, the data gathering unit 712 may use the product identifier contained in the received request to determine whether a digital twin associated with said product identifier is already contained in DT storage 720. This avoids generation of digital twins for products, for which digital twins are already existing in DT storage 720 (e.g. for which a digital twin has already been generated previously).

Apparatus 702 may further comprise digital twin generator 716 configured to generate the digital twin including a decentral digital twin identifier, such as a decentral digital twin identifier provided by decentral ID generator 718, and one or more digital twin data set(s), such as digital twin data set(s) generated by

aspect agent 714. The decentral identifier may include one or more DID(s) and/or one or more UUID(s). The one or more DID(s) and/or UUID(s) may be associated with the digital twin and/or the digital twin data set(s) contained in the digital twin. The one or more DID(s) and/or UUID(s) may further be associated with the product. The digital twin generator 716 may be configured to generate the digital twin according to the method described in the context of FIG. 8 and FIG. 10. Digital twin generator 716 may be configured to request the decentral digital twin identifier. Said request may include at least one authentication mechanism or may include selecting at least one of multiple authentication mechanisms. The request may include an owner identifier and/or a chemical product identifier and/or access data. The digital twin generator 716 may be configured to generate the access data. Access data may include digital representation(s) pointing to the digital twin data set(s). Access data may further include digital twin data set identifier(s). The digital twin generator 716 may be configured to assign the decentral digital twin identifier received from decentral ID generator 718 to at least part of the digital twin data sets generated by aspect agent 714. For instance, the digital twin generator 716 may assign the product identifier contained in at least part of the digital twin data sets to the received decentral digital twin identifier such that at least part of the digital twin data sets of the product are associated with the decentral digital twin identifier. Assigning may include interrelating the decentral digital twin identifier with at least part of the digital twin data sets associated with the product and stored in DT storage 720, such as digital twin data sets stored by aspect agent 714 in DT storage 720 as outlined below. The digital twin generator 716 may be configured to assign the decentral digital twin identifier received from decentral ID generator 718 to digital twin data set identifier(s) associated with at least part of the digital twin data set(s) generated by aspect agent 714. The digital twin generator 716 may be configured to provide the generated digital twin or a part thereof (e.g. digital twin data set(s), also denoted as assets or aspects of the digital twin hereinafter) to digital twin provider 722. The digital twin generator 716 may be configured to provide the decentral digital twin identifier and access data associated with the digital twin to the digital twin provider 722. The digital twin generator 716 may be configured to provide access rules associated with each digital twin or each digital twin data set to the digital twin provider 722 as described later on.

Apparatus 702 may further comprise a decentral ID generator 718 configured to generate and provide a decentral digital twin identifier associated with the data gathered by data gathering unit 712 and optionally a data owner, such a data owner of the gathered data. The decentral ID generator 718 may be configured to generate – apart from the decentral digital twin identifier – digital twin data set identifier(s). The decentral ID generator 718 may be communicatively coupled to apparatus 702, e.g. apparatus 702cmay not comprise said decentral ID generator 718 (not shown). The decentral digital twin identifier may further be associated with a data owner of the gathered data and/or the digital twin data set(s), such as the entity operating production 104. Decentral ID generator 718 may be a central or decentral network node configured to generate a decentral identifier, such as a DID or UUIDv4 as described in the context of FIG. 13. Decentral ID generator 718 may be computing node that acts as a DID owner's management module, user agent, ID hub and/or certification issuer. Decentral ID generator 718 may be configured to receive

a request to provide a decentral digital twin identifier associated with the data gathered by data gathering unit 712 and optionally a data owner. Said request may include at least one authentication mechanism or may include selecting at least one of multiple authentication mechanisms. The request may include an owner identifier and/or a product identifier and/or access data as previously described. Decentral ID generator 718 may be configured to generate the decentral digital twin identifier as well as data related to the authentication mechanism and to provide the generated digital twin decentral identifier and data related to the authentication mechanism to digital twin generator 716.

Aspect agent 714 may be configured to retrieve or receive - based on data contained in the received request - a generated digital twin template from template DB 506. Template DB 506 may store digital twin templates. The digital twin templates may be generated by apparatus for generating DT templates 116 as described in the context of FIG. 5. The digital twin templates may be generated according to the method described in the context of FIG. 6A or FIG. 6B. The digital twin template may be provided based on a product identifier contained in the received request. Aspect agent 714 may be configured to receive or retrieve - based on the respective digital twin template - at least one aspect model from a model DB 418 connected via a communication interface to the aspect agent 714. Model DB 418 may be part of decentral network 514 as described in the context of FIG. 5. Each aspect model may include the structure of at least a portion of the digital twin data set, and/or properties of the digital twin data set.

Aspect agent 714 may be configured to generate – for each retrieved or received aspect model – a digital twin data set associated with the product by applying each retrieved or received aspect model to the gathered data received from digital twin generator 716 (see for example FIG. 9). For instance, the aspect agent 714 may map the gathered data to the structure and/or properties of the respective aspect model. Aspect agent 714 may be configured to store at least part of the generated digital twin data sets in the DT storage 720. This allows to avoid unnecessary data transfer between aspect agent 714 and the digital twin generator 716. Moreover, this allows to separate the digital twin generation and the digital twin accessing, hence improving the overall stability and availability of the digital twin generation and provision. At least part of digital twin data sets may contain a product identifier to allow linkage of the generated digital twin data set(s) to the respective product. For instance, each generated digital twin data set may include the same product identifier.

Each digital twin data set associated with the decentral digital twin identifier of the digital twin may be regarded as an asset or aspect of the digital twin. Each asset or aspect may be uniquely identified by a digital twin data set identifier. Hence, the combination of decentral digital twin identifier and digital twin data set identifier may allow to uniquely identify a digital twin data set associated with a product. Moreover, said combination also allows to specifically retrieve such digital twin data set, for example via a decentral data consuming network node using the decentral digital twin identifier, the digital twin data set identifier and access data as described in the context of FIG. 15.

The apparatus 702 may further comprise DT storage 720 configured to store the digital twin data set(s) generated by aspect agent 714. DT storage 720 may be configured to store data associated with the product gathered by data gathering unit 712. The digital twin data set(s) stored in DT storage 720 may be interrelated with the decentral digital twin identifier provided by decentral ID generator 718 to allow retrieval of said digital twin data set(s) based on the decentral digital twin identifier. The digital twin data set(s) may be further interrelated with the digital twin data set identifier(s) to allow retrieval of a specific digital twin data set based on the decentral digital twin identifier in combination with the digital twin data set identifier(s). This allows to retrieve specific assets or aspects of the digital twin without having to provide all data contained in the digital twin. Moreover, this allows to define access rights on asset/aspect level, thus allowing a more granular control of access to the data contained in the respective asset/aspect of the digital twin.

The apparatus 702 may further comprise a digital twin provider 722 configured to provide the digital twin or a part thereof generated by digital twin generator 716 for access, for example by a decentral data consuming network node associated with a consumer of the chemical product (see also FIG. 15). The digital twin provider may be a decentral data providing network node. The apparatus 702 may be communicatively coupled to digital twin provider 722 configured to provide the digital twin generated by digital twin generator 716 for access (not shown, see for example FIG. 7B). The digital twin provider 722 may be configured to receive the generated digital twin or a part thereof (e.g. assets or aspects of the digital twin) from digital twin generator 716. The digital twin provider 722 may be configured to receive the decentral digital twin identifier and access data associated with the digital twin from digital twin generator 716. Digital twin provider 722 may store the received data in a database (not shown). This may allow digital twin provider 722 to retrieve the digital twin or a part thereof, for example from DT storage 720, and provide the respective data to a decentral data consuming network node, for example as described in the context of FIG. 8 and FIG. 15. For instance, the database may store the decentral digital twin identifier associated with each digital twin and the access data. Storing access data for each digital twin data set in combination with the decentral digital twin identifier allows to avoid unnecessary data traffic, since only the requested digital twin data set and not the complete data contained in the digital twin needs to be retrieved upon request, for example by a decentral data consuming network node. Based on the decentral digital twin identifier and the access data stored in the database, digital twin provider 722 may retrieve the digital twin or a part thereof from DT storage 720 and may provide the retrieved data to a decentral data consuming network node.

Digital twin provider 722 may be configured to receive access rules associated with each digital twin or a part thereof from digital twin generator 716. Digital twin provider 722 may be configured to store the received access rules in a database of digital twin provider 722 . The access rules may include a list of decentral participant identifiers associated with decentral data consuming network nodes allowed to access the data contained in the digital twin or the digital twin data set(s). The access rules may include usage policies defining processing, aggregating or forwarding data of the digital twin or data of the digital

twin data set(s). The access rules may be associated with the decentral digital twin identifier of the digital twin and/or the digital twin data sets of the digital twin. The access rules may be further associated with the digital twin data set identifier(s).

The usage policies may be bound to data being exchanged and enforcement of attached usage policies may be continuously controlled, for example by the decentral data consuming network node receiving the data or by a decentral data processing network node processing received data. Usage policies may be instantiated on the target system. Usage policies may be adhered to the data (also called sticky policy). Sticky policies are one way to cope with the distribution of the usage restrictions. In this approach, machine-readable usage policies may stick to data when it is exchanged. There exist different realization possibilities. For instance, data may be encrypted and can only be decrypted when the adherence to the usage restrictions are guaranteed.

Usage policies may include additional information provided e.g. by a policy information registry. Additional information may include information about contextual information such as previous data usages or the geographical location of an entity, pre- or post-conditions that have to hold before (e.g. integrity checks) and after (e.g. data item is deleted after usage) the decision-making and on-conditions that have to hold during usage (e.g. only during business hours). For instance, the policy information registry may be used to resolve the ID of a supplier to a postal address and the postal address to GPS coordinates.

Usage control may be implemented by encrypting the data within a decentral network node connected to a storage infrastructure before transferring the data to the storage infrastructure. Using the data is only possible by using the decentral network node to decrypt the data. Hence, every usage is controlled by the decentral network node. In such cases, usage restrictions such as data lifetime or time constraints can be enforced by deleting the cryptographic key material. Additionally or alternatively, the storage infrastructure may include a usage control enforcement component that monitors and/or controls the usage of the data.

FIG. 7B illustrates an example of a layered system for generating a digital twin of a physical entity of a product. The product may be chemical product. The layered system may be included in operating system 108 of a production 104 producing products 106from one or more inbound materials 102 (see for example FIG. 1A and FIG. 1B). At least part of the layered system may be included in operating system 108 while another part may be communicatively coupled to said operating system 108 (see for example FIG. 1C).

The layered system may comprise a data source layer 704, such as the data source layer 704 described in the context of FIG. 7A. The data source layer 704 may comprise one or more distributed data sources 706, 708, 710. The distributed data sources may contain data instances that relate to products 106 produced by production 104 as described in the context of FIG. 2 and FIG. 7A.

The system may further comprise a service layer 724, this layer generally being optional. The service layer may be configured to gather data associated with products from data source layer 704. The service layer may be configured to gather data according to predefined selection criteria. The service layer may be configured to apply one or more semantic models on the gathered data to generate a uniform data collection. The service layer may be configured to provide the uniform data collection to a data streaming platform included in the service layer. The streaming platform may include a platform that is deployed across a number of hosts, clusters, data centers, and/or other collections of computing resources. The streaming platform may include one or more client processes that generate records of activity and publish the records to one or more event streams. For instance, when a certain type of activity occurs in data source layer 704, for example provision of a new uniform data collection, production of a new batch of chemical product, collection of new data associated with produced chemical product, etc., the one or more client processes may generate a record of the activity and publish said record to one or more event streams. The data streaming platform may then propagate the record to one or more components subscribing to the same event streams(s). The data propagated to one or more components may be stored in a database present within the service layer or the consumer layer. The data streaming platform thus allows activity occurring in multiple distributed data sources of data source layer 704 to be captured and transmitted in a unified, scalable manner.

The system may further comprise a consumer layer 726. Consumer layer 726 may include an apparatus for generating digital twin(s), such as apparatus 702 described in the context of FIG. 7A. Consumer layer 726 may be configured to gather data associated with the product from data source layer 704, for example as described in the context of FIG. 7A. Consumer layer 726 may be configured to consume data from the service layer 724, for example from one or more database(s) of service layer 724 comprising the data stored by consumer components of the data streaming platform of service layer 724. Consumer layer 726 may be configured to generate digital twins of products from the data gathered from data source layer 704 or data consumed from service layer 724 as described in the context of FIG. 7A, FIG. 9 and FIG. 10. Consumer layer 726 may be connected to an input/output device (not shown), for example I/O device 510 of FIG. 7A. I/O device 510 may be used to trigger generation of a digital twin of a product as described in the context of FIG. 7A.

The system may further comprise a connector layer 728. Connector layer 728 may be configured to provide the digital twin or a part thereof generated in consumer layer 726 for access. Connector layer 728 may comprise digital twin provider 722, such as a decentral data providing network node described in the context of FIG. 8 and FIG. 15, configured to provide access to the digital twin or a part thereof. The access may be controlled via digital twin provider 722 by the data owner of the digital twin or a part thereof, for example by access rules associated with the digital twin or a part thereof as described in the context of FIG. 7A. Digital twin provider 722 of connector layer 728 may be configured to exchange data, such as data contained in the digital twin, with a decentral data consuming network node. The decentral data consuming network node may be associated with a consumer or processor of the product (see for

example FIG. 15). The decentral data providing network node and the decentral data consuming network node may perform authentication steps prior to exchange of data. Digital twin provider 722 may apply access rules associated with the digital twin or a part thereof requested by the decentral data consuming network node prior to providing said data to said decentral data consuming network node, for example as described in the context of FIG. 7A. Digital twin provider 722 may deny access to the digital twin or a part thereof based on said access rules. Digital twin provider 722 may grant access to the digital twin or a part thereof based on said access rules. Digital twin provider 722 may modify access to the digital twin or a part thereof based on said access rules. The access may be granted for all data contained in the digital twin (e.g. all data associated with the decentral digital twin identifier) or a part thereof, such as specific digital twin data set(s) contained in the digital twin.

The layered system allows to achieve availability, integrity and confidentiality of the data contained in a digital twin or the digital twin data set(s). The connector layer allows to configure and ensure technically that only predefined decentral network participants can access and retrieve data associated with the digital twin. For instance, separation of the digital twin generation and the consumption of data contained in the digital twin allows to achieve a high and stabile availability of data contained in the digital twin within the decentral network.

FIG. 8 illustrates an example system and associated methods for generating a digital twin associated with a product produced by a production and providing access to the generated digital twin. The product may be a chemical product. The digital twin may be generated using a digital twin template. The digital twin template may be generated by apparatus for generating DT templates 116 described int the context of FIG. 5. The digital twin template may be generated according to the method described in the context of FIG. 6A and FIG. 6B. The apparatus for generating digital twin(s) may be apparatus 702 described in the context of FIG. 7A. The apparatus for generating digital twin(s) may be included in operating system 108 of production 104 (see for example FIG. 1A, FIG. 1B). The apparatus for generating digital twin(s) of product(s) may be communicatively coupled to operating system 108 of production 104 (see for example FIG. 1C). The digital twin may be generated by the system described in the context of FIG. 7B

The production 104 may be chemical production described in relation to FIG. 1A to FIG. 2. Production 104 may produce at least one product 106 from one or more inbound material(s) 102. The inbound materials may be provided to production 104, for example as described in the context of FIG. 1A to FIG. 1C. The inbound materials may enter the system boundary 802 of production 104 at the entry point, such as a production plant or a material storage associated with production 104. The amount of inbound material entering the system boundary 802 of production 104 may be measured, for example using sensor 110b described in the context of FIG. 1A to FIG. 1C. Chemical and/or physical properties of the inbound material may be measured, for example using sensor 110a described in the context of FIG. 1A to FIG. 1C, upon passing system boundary 802 of production 104. The measured data may be used to determine at least one chemical and/or physical property of the inbound material.

The inbound materials may be used in production 104 to produce one or more product(s) 106 from the inbound materials 102, for example as described in the context of FIG. 1A to FIG. 1C. Operating system 108 of production 104 may monitor and/or control the chemical production based on operating parameters of the different processes. Operating system 108 may receive production demand data associated with the production planning for production 104. The production demand data may be produced from target production capacities for one or more chemical product(s) produced by production 104. The production demand data may be produced from pre-defined production capacities or data-driven models that relate production capacities to market demand data or quantities consumed at the consumption location. The production demand data may include target capacities for products produced by production 104. Operating system 108 may further receive a bill of materials associated with products to be produced. The bill of materials may include material data associated with the materials used to produce the product, process data associated with the production chain for producing the product and/or product data associated with the product, such as a product specification data or data on the amount of product to be produced.

Based on the received production demand data and the bill of materials, material demand data may be determined. The material demand data may include data on the amount of material required to produce the target capacities of the product 106. The material demand data may include material identifiers associated with materials required to produce the product 106 and data on amounts of material for respective materials. The material demand data may include one or more material specifier(s) per material identifier signifying the material specification. The material demand data may include data on the material amount per material identifier signifying the amount of material to be supplied. The material demand data may specify the production chain(s) of production 104. The material demand data may include a bill of materials for one or more production chain(s) of production 104. The material demand data may include one or more recipe(s) specifying one or more material(s) for production process(es) of production 104. The determined material demand data may be provided for access by a supplier system associated with a supplier outside the physical system boundary of production 104. Material supply may be triggered by the supplier system accessing the material demand data.

The amount of product(s) 106 resulting from processes performed within production 104, such as chemical reactions and/or physical processing and/or assembly processes, may be measured using a sensor, such as sensor 110a described in the context of FIG. 1A to FIG. 1C. Since chemical reactions may result in more than one reaction product, e.g. a chemical reaction is associated with a many-to-many relationship between starting materials and resulting reaction products (see also FIG. 1A to FIG. 1C), measuring the amount of chemical product(s) resulting from each chemical reaction performed within the chemical production allows to track material flows within the chemical production. The measured data may be stored in one or more databases associated with operating system 108. Moreover, chemical reactions and/or physical processes may be monitored using sensors, such as sensors 110b, and the generated monitoring data may be stored in one or more databases associated with operating system

108. The measured amounts of produced products as well as the monitoring data may be used to generate a digital twin of each production process performed within production 104. The measured amounts of produced products as well as the monitoring data may be used to generate a digital twin of the production 104. This digital twin allows to reliably track and account for flows of inbound material, intermediate chemical products and chemical products despite the many-to-many relationships between starting materials and reaction products associated with chemical reactions. Physical and/or chemical properties of produced products may be measured by sensors, such as sensors 110a, and/or determined as described in the context of FIG. 1A to FIG. 1C. The measured and/or determined chemical and/or physical properties of the produced products 106 may be stored in one or more databases associated with operating system 108.

The produced products 106 may be provided at one or more exit points of production 104. The product 106 may exit the system boundary 802 of production 104. Upon producing the product 106 or upon exiting of the product 106 of production 104, the digital twin may be generated. The apparatus 702 may be configured to generate the digital twin as described in the context of FIG. 7A and FIG. 10. A requestor 804 may be configured to generate the request to generate the digital twin. The requestor 804 may be included in a labelling device, for example as described in the context of FIG. 2. The request may contain data related to the product, such as a batch number. The request to generate the digital twin may be provided to data gathering unit 712 of apparatus 702. In response to the request, data gathering unit 712 may be configured to gather data associated with the product, for example from a data layer such as data source layer 704 (not shown, see for example FIG. 7A and FIG. 7B), based on the data contained in the received request (see FIG. 7A, FIG. 7B). The data gathering unit 712 may be configured to determine whether a digital twin associated with the produced product 106 is already contained in DT storage 720 (see FIG. 7A). The request to generate the digital twin may be provided to digital twin generator 716 of apparatus 702 (not shown). In response to the request, digital twin generator 716 may be configured to initiate gathering of data associated with the product by data gathering unit 712.

Data gathering unit 712 may provide the gathered data to digital twin generator 716. Digital twin generator 716 may be configured to request a decentral digital twin identifier associated with the gathered data and optionally a data owner from decentral ID provider 806, for example as described the context of FIG. 7A. Digital twin generator 716 may be configured to retrieve digital twin data set(s) from aspect agent 714. Digital twin generator 716 may be configured to generate the digital twin as described for example in the context of FIG. 7A and FIG. 10. The digital twin may include the decentral digital twin identifier and the digital twin data sets generated by aspect agent 714. Digital twin generator 716 may be configured to provide the generated digital twin to digital twin provider 722.

Aspect agent 714 may be configured to retrieve or receive - based on data contained in the received request - a generated digital twin template from template DB 506 as described in the context of FIG. 7A. Template DB 506 may store digital twin templates. The digital twin templates may be generated by

apparatus for generating DT templates 116 as described in the context of FIG. 5. The digital twin templates may be generated according to the method described in the context of FIG. 6A or FIG. 6B. Aspect agent 714 may be configured to receive or retrieve - based on the respective digital twin template - at least one aspect model from a model DB 418 connected via a communication interface to the aspect agent 714 (not shown). Model DB 418 may be part of decentral network 514 as described in the context of FIG. 5.

Aspect agent 714 may be configured to generate digital twin data set(s) for each retrieved or received aspect model (see for example FIG. 9). Aspect agent 714 may be configured to store the generated digital twin data sets in DT storage 720 (see FIG. 7A). Aspect agent 714 may be configured to provide at least part of the generated digital twin data set(s) to digital twin generator 716.

Decentral ID generator 718 may be configured to generate a decentral digital twin identifier associated with the gathered data and optionally a data owner, such a data owner of the data associated with the product. Decentral ID generator 718 may be configured to generate a decentral identifier including or being associated with further identifier, such as data set identifier(s). For instance, decentral ID generator 718 may be configured to generate a digital twin identifier, such as a DID or a UUID. Decentral ID generator 718 may be configured to generate digital twin data identifier(s), such as DID(s) and/or UUID(s). Decentral ID generator 718 may comprise a component configured to generate Decentralized Identifier(s) (DID(s)). Decentral ID generator 718 may comprise a component configured to generated Universally Unique Identifiers (UUID(s)). The decentral identifier generated by decentral ID generator 718 may be one or more DID(s) and/or UUID(s). The one or more DID(s) and/or UUID(s) may be associated with the digital twin and/or the digital twin data set(s). The one or more DID(s) and/or UUID(s) may further be associated with the product. For instance, the decentral digital twin identifier may include a digital twin identifier associated with the digital twin and one or more digital twin data identifier(s) associated with digital twin data. The decentral identifier may further include a product identifier associated with the chemical product. Decentral ID generator 718 may be a central or decentral node or a computing node as described in the context of FIG. 7A. The decentral digital twin identifier may be requested by digital twin generator 716. The decentral digital twin identifier may be requested by the decentral ID provider 806, for example upon receiving a request from the digital twin generator 716 (not shown). Decentral ID generator 718 may be part of the apparatus 702. Decentral ID generator 718 may be communicatively coupled to apparatus 702 (not shown). Decentral ID generator 718 may be configured to provide the generated decentral digital twin identifier to decentral ID provider 806. Decentral ID generator 718 and the decentral ID provider 806 may be separate devices as illustrated in FIG. 8. Decentral ID generator 718 and the decentral ID provider 806 may be contained within one device configured to generate the decentral identifier and to provide the generated decentral identifier, for example as illustrated in FIG. 7A.

Decentral ID provider 806 may be configured to provide the received decentral digital twin identifier to the requestor 804configured to associate the received decentral digital twin identifier with the product. For this purpose, the requestor 804 may include an ID assignor (see for example FIG. 1B, FIG. 1C, FIG. 2). Decentral ID provider 806 may be configured to provide the received decentral digital twin identifier to an ID assignor configured to associate the received decentral identifier with the product (not shown). Such association may include encoding the decentral identifier into a code, such as a bar code, a QR code, an embossed code, an optical holographic identifier, and providing the generated code for labelling of the product. This way a physical identifier may be provided that relates the physical entity of the product with the decentral digital twin identifier and hence the digital twin with the physical entity of the product.

Digital twin provider 722 may be configured to provide the digital twin or a part thereof for access by a decentral data consuming network node 808. Decentral data consuming network node 808 may be part of a decentral network 514. The digital twin or a part thereof may be accessed by the decentral data consuming network node 808 using at least the decentral digital twin identifier. Access to the digital twin or a part thereof may be controlled by digital twin provider 722 (see for example FIG. 15). Digital twin provider 722 may be associated with the data owner of the digital twin data set(s). Digital twin provider 722 may be associated with the data owner of the digital twin. Digital twin provider 722 may be associated with the operator of production 104. Digital twin provider 722 may be a decentral data providing network node.

FIG. 9 illustrates an example apparatus for generating a digital twin of a physical entity of a product using a digital twin template defining three different aspect models. The digital twin template used to generate the digital twin may define more or less aspect models. The product may be a chemical product. The apparatus may correspond to the apparatus 702 described in the context of FIG. 4A. The apparatus may be included in operating system 108 of production 104 producing products 106 from one or more inbound materials 102 (see for example FIG. 1A and FIG. 1B). The apparatus may be communicatively coupled to operating system 108 of production 104 producing products 106 from one or more inbound materials 102 (see for example FIG. 1C). The apparatus may be configured to generate a digital twin 912, for example as described in the context of FIG. 7A and FIG. 10. The apparatus of FIG. 9 may be connected to data source layer 704 as described in the context of FIG. 7A.

The apparatus may comprise a data gathering unit 712 configured to gather data associated with a product for which a digital twin is to be generated from data source layer 704, for example as described in the context of FIG. 7A and FIG. 10. The gathered data may be provided to digital twin generator 716. The gathered data may be retrieved by digital twin generator 716.

Digital twin generator 716 may be configured to request a decentral digital twin identifier from decentral ID generator 718, for example as described in the context of FIG. 7A to FIG. 10. Digital twin generator 716 may be configured to provide data gathered by data gathering unit 712 to aspect agent 714. Digital

twin generator 716 may be configured to retrieve or receive digital twin data set(s) generated by aspect agent 714. Digital twin generator 716 may be configured to retrieve or receive digital twin data set(s) from DT storage 720. Digital twin generator 716 may be configured to generate the digital twin of the product from the received decentral digital twin identifier and at least part of the received or retrieved digital twin data set(s), for example as described in the context of FIG. 7A and FIG. 10. For instance, digital twin generator 716 may associate the received decentral digital twin identifier with each of the generated digital twin data sets 906, 908, 910 to generate the digital twin 912. Hence, the decentral identifier allows to identify all digital twin data sets included in a digital twin 912 of a product. Each digital twin data set may be uniquely identified by a digital twin data set identifier in combination with the decentral digital twin identifier as described in the context of FIG. 7A. Digital twin generator 716 may be configured to generate access data, for example as described in the context of FIG. 7A. Digital twin generator 716 may be configured to generate a DID document containing the decentral digital twin identifier (e.g. DID) received from decentral ID generator 718 and access data, such as chemical digital twin data set identifier(s) and respective digital representation(s) pointing to said digital twin data set(s). Digital twin generator 716 may be configured to store the generated digital twin 912 in the DT storage 720 as described in the context of FIG. 7A and FIG. 10. Digital twin generator 716 may be configured to provide the generated digital twin 912 to digital twin provider 722 as described the context of FIG. 7A and FIG. 10 (not shown).

Aspect agent 714 may be configured to retrieve or receive a digital twin template (DT template 902). The digital twin template may be generated by apparatus for generating DT templates 116 as described in the context of FIG. 5. The digital twin template may be generated by the method described in the context of FIG. 4A, FIG. 4B, FIG. 6A and FIG. 6B. The digital twin template may define one or more aspect models. In this embodiment, DT template 902 defines three different aspect models. In another embodiment (not shown), DT template 902 may define more or less aspect models. DT template 902 may include the three aspect models. DT template 902 may include a digital representation pointing to the respective aspect models. The digital representation may be used by aspect agent 714 to retrieve or receive respective aspect models from model DB 418, for example as described in the context of FIG. 5. Aspect agent 714 may be configured to generate – for each aspect model contained in DT template 902 – a digital twin data set from the gathered data received from data gathering unit 712 according to the respective aspect model. Each digital twin data set 906, 908, 910 may be associated with the respective aspect model used for its generation. Aspect agent 714 may be configured to store the generated digital twin data set(s) and associated data, such as digital twin data set identifier(s), in DT storage 720 (see FIG. 7A). Aspect agent 714 may be configured to provide at least part of the generated digital twin data set(s) to digital twin generator 716.

Decentral ID generator 718 may be configured to generate and provide a decentral digital twin identifier to digital twin generator 716 as described in the context of FIG. 7A and FIG. 10. Decentral ID generator 718 may be a central node or a decentral node and may generate the decentral digital twin identifier upon

receiving a request from digital twin generator 716 (see for example FIG. 7A). Decentral ID generator 718 may be configured to generate access data, such as digital twin data set identifier(s).

FIG. 10 illustrates a flow chart of a computer-implemented method for generating a digital twin of a physical entity of a product in accordance with an example embodiment of the present disclosure. The product may be a chemical product. The digital twin may be generated for a product 106 produced by production 104 from one or more inbound materials 102. Production 104 may be a chemical production as described in relation to FIG. 1A to FIG. 2. The digital twin may be generated by operating system 108 of production 104. Operating system 108 may comprise an apparatus for generating digital twin(s) 702 as described in the context of FIG. 7A to FIG. 8. The request to generate the digital twin may be triggered manually by a user via a user interface, for example using I/O device 510 (see FIG. 7A). The request to generate the digital twin may be triggered automatically, for example upon detection of a packaging of the produced product as described in the context of FIG. 2 and FIG. 8.

In block 1002, a request to generate a digital twin of the product may be received. The request may contain data related to the product. The request may be generated manually or automatically, as previously described. Data related to the product may include a product identifier, such as a batch number, a LOT number, a product name and/or a product ID.

In decision block 1004, it may be determined whether a digital twin for the product is already existing. Hence, it may be determined whether the digital twin has already been generated and stored, for example in DT storage 720. This determination may be based on the data related to the product contained in the received request, such as the product identifier. For instance, the product identifier may be used to determine whether a digital twin associated with said product identifier is already existing, e.g. already stored in DT storage 720. If a digital twin of the product is already existing, the method may proceed to decision block 1006. Otherwise, the method may proceed to block 1010 as described later on.

In decision block 1006, it may be determined whether the existing digital twin is to be updated. The determination may be made based on data contained in the received request. For instance, the request may contain data being indicative of updating the digital twin. If an existing digital twin is to be updated, the method may proceed to block 1008. Otherwise, the method may end or may proceed to block 1002.

In block 1008, the digital twin may be updated. Updating may include performing block 1010, block 1014 and block 1016 described later on, e.g. generating further digital twin data set(s). Updating may include changing data contained in the existing digital twin or existing digital twin data set(s) or adding data to existing digital twins or existing digital twin data set(s).

In block 1010, data associated with the product may be gathered from one or more distributed data sources based on the data related to the product contained in the request received in block 1002. The gathered data may contain at least one measured and/or determined physical and/or chemical property

of the product. The data may be gathered as described in the context of FIG. 7A to FIG. 8 from one or more distributed data sources, for example distributed data sources of data source layer 704. The data may be gathered directly from the one or more distributed data sources of data source layer 704, for example as described in the context of FIG. 4A. The data may be consumed the data from service layer 724, for example as described in the context to FIG. 7B.

In block 1012, a decentral digital twin identifier associated with the gathered data and optionally a data owner may be provided. The decentral digital twin identifier may be provided in response to a request generated, for example, by digital twin generator 716 (see FIG. 7A, FIG. 8). The request may contain a data owner identifier and/or a product identifier. The data owner may be the data owner of the gathered data and/or the data contained in the distributed data sources. The data owner may be the product producer. The data owner may be a data owner as previously described. The decentral digital twin identifier may be requested from a central or decentral node, for example as described in the context of FIG. 7A. The decentral identifier may be one or more DID(s) and/or UUID(s), for example as described in the context of FIG. 7A. Block 1012 may also be performed after any one of block 1014 and block 1016.

In block 1014, a digital twin template to be applied to the gathered data may be provided. The digital twin template may be generated by the apparatus described in the context of FIG. 5. The digital twin template may be generated by the method described in the context of any one of FIG. 4A, FIG. 4B, FIG. 6A and FIG. 6B. The digital twin template may be provided based on data contained in the request received in block 1002, for example based on the product identifier. The digital twin templates may be stored in a database, such as template DB 506, and may be provided based on data contained in the received request.

In block 1016, aspect model(s) defined in the provided digital twin template may be applied to the gathered data. The aspect model(s) may be defined in the digital twin template. The aspect models may be retrieved or received from a database, such as model DB 418, based on digital representations included in the digital twin template (see also FIG. 9). Applying the aspect model(s) defined in the digital twin template to the gathered data may result in generation of digital twin data set(s). A digital twin data set may be generated for each aspect model defined in the digital twin template, for example as described in the context of FIG. 7A and FIG. 8.

In block 1018, the digital twin may be generated. The digital twin may include the decentral digital twin identifier provided in block 1012 and the digital twin data set(s) generated in block 1016. The decentral digital twin identifier may be linked to at least part of the digital twin data set generated in block 1016 to generate the digital twin (see for example FIG. 9). The generated digital twin may contain digital twin data set identifier(s). The digital twin data set identifier(s) may be generated by digital twin generator 716 (see for example FIG. 7A, FIG. 8). The digital twin may further include a product identifier. The product identifier may be the product identifier contained in the received request. The generated digital

twin may be stored in a DT storage 720 as described in the context of FIG. 7A. Storage of the digital twin in DT storage 720 may improve security with respect to the access to the digital twin, since appropriate authentication and authorization schemes may be implemented between DT storage 720 and digital twin provider 722 providing the digital twin or a part thereof to authorized decentral data consuming network nodes. The generated digital twin and/or digital twin data set(s) contained therein may be provided to digital twin provider 722 as described in the context of FIG. 7A and FIG. 8.

In block 1020, the generated digital twin may be provided to decentral data consuming network nodes under control of digital twin provider 722, this block being generally optional. The digital twin may be provided to decentral data consuming network node(s) as described in the context of FIG. 15.

In block 1022, a physical identifier may be assigned to the decentral digital twin identifier included in the digital twin, this block being generally optional. This block may be performed, for example, if the decentral digital twin identifier contained in the digital twin is used to generate the digital access element (see for example FIG. 11 and FIG. 12). This allows to link the decentral digital twin identifier and thus the digital twin to the physical entity of the product. Assigning the decentral digital twin identifier to the physical identifier may include generating a physical identifier having embedded the decentral digital twin identifier. The physical identifier may be generated by an ID assignor, for example as described in the context of FIG 5 and may be attached to the chemical product, for example using a labelling device.

FIG. 11 illustrates a flow chart of a method for generating a digital access element associated with a digital twin of a product in accordance with an example embodiment of the present disclosure. Since the digital twin is associated with the physical entity of the product, the digital access element is also, at least indirectly, associated with the physical entity of the product. The product may be a chemical product. The digital access element may allow for an indirect access to the digital twin or a part thereof, i.e. an access to digital twin via the digital access element. Access to the digital access element itself can remain unrestricted while still allowing for controlled access to the digital twin or parts thereof. The product 106 may be produced by production 104 from one or more inbound materials 102. Production 104 may be a chemical production as described in the context of FIG. 1A to FIG. 2. The production may comprise or be associated with operating system 108. Operating system 108 may comprise an apparatus for generating digital twin(s) as described in the context of FIG. 7A to FIG. 8. Operating system 108 may comprise an apparatus for generating digital access element(s) as described in the context of FIG. 12. Operating system 108 may be communicatively coupled to the apparatus for generating digital twin(s) and/or for generating digital access element(s). The digital access element may correspond to a DID document associated with the DID used to generate the digital twin. Such DID document may contain the DID contained in the generated digital twin, digital twin data set identifiers associated with digital twin data sets contained in the digital twin and access data. Access data may include digital representations pointing to the digital twin data set(s) as described in the context of FIG. 7A. The digital access element may correspond to a DID document associated with a further decentral identifier. The digital access

element may correspond to a data structure comprising a decentral digital twin identifier, further identifier(s) such as a digital twin data set identifier, and access data, for example as illustrated in FIG. 13.

In block 1102, a digital twin of a physical entity of a product may be generated. The digital twin may be generated by the method described in the context of FIG. 10. Block 1102 may be performed using an apparatus for generating digital twin(s) as described in the context of FIG. 7A to FIG. 8. The generated digital twin may be stored on a data storage medium, such as DT storage 720.

In block 1104, a request to provide a decentral access element identifier associated with the digital twin may be received. The decentral identifier may further be associated with a data owner. The data owner may be the data owner of the digital twin data set(s) contained in the digital twin as described previously. The data owner may be the product producer as described previously. The decentral access element identifier may be a DID. The decentral access element identifier may be a UUID. The request may be generated by a requestor, for example as described in the context of FIG. 12. The request may contain an owner identifier and/or a product identifier as previously described.

In decision block 1106, it may be determined whether a further decentral identifier is to be provided. The decision may be based on data, such as a decentral digital twin identifier, contained in the digital twin generated in block 1102. For instance, the method may proceed to block 1110 if the decentral digital twin identifier contained in the digital twin is a DID. Use of the decentral digital twin allows to avoid generation of a further decentral identifier, hence allowing a more effective generation of the digital access element. The decision may be based on the programming of the routine implementing the method. For instance, the routine may be programmed to provide a further decentral identifier. Use of a further decentral identifier allows to use different identifier schemes, such as UUID and DID. This may allow to store access data necessary to access the digital twin or a part thereof in a decentralized manner using a DID document (see for example FIG. 13). If a further decentral identifier is to be provided, the method proceeds to block 1108. Otherwise, the method proceeds to block 1110.

In block 1108, a further decentral identifier may be provided. This may include generating a further decentral identifier and providing the generated further decentral identifier, for example as described in the context of FIG. 12. The further decentral identifier may be assigned to the decentral digital twin identifier. This allows to link the digital twin with the digital access element, hence allowing access the digital twin or a part thereof using the digital access element. The further decentral identifier may be a DID. The further decentral identifier may be assigned to the decentral digital twin identifier. This may allow to link the digital twin to the respective digital access element.

In block 1110, the decentral digital twin identifier contained in the digital twin generated in block 1102 may be retrieved. The retrieved decentral digital twin identifier may then be provided. For instance, the decentral digital twin identifier included in the generated digital twin may be retrieved from DT storage

720. The respective digital twin may be identified using the product identifier contained in the request received in block 1104. For instance, the product identifier may be used to retrieve the decentral digital twin identifier contained in the digital twin associated with said product identifier.

In block 1112, the digital access element associated with the produced product may be generated. The generated digital access element may include the decentral digital twin identifier included in the digital twin or the further decentral identifier, and access data. If the decentral digital twin identifier is a DID, the generated digital access element may correspond to a DID document associated with the DID. The access data may refer to any data for accessing the digital twin or a part thereof as previously described. For instance, the access data may include an endpoint for data exchange or sharing (resource endpoint) or an endpoint for service interaction (service endpoint), that is uniquely identified via a communication protocol. The endpoint may be represented by digital twin provider 722 (see for example FIGs. 8 and FIG. 12). The access data may include multiple digital representations, each digital representation pointing to a different digital twin data set contained in the digital twin. The respective decentral identifier and the access data may be associated with each other. Hence, for instance, the decentral identifier based on which the digital access element is generated may be associated with authentication information which is used as access data based on which the digital access element is generated.

In block 1114, a physical identifier associated with the product may be assigned to the decentral digital twin identifier/further decentral identifier included in the digital access element generated in block 1112, this block generally being optional. This allows to link the digital access element and hence the digital twin associated with the decentral digital twin identifier or indirectly associated with the further decentral identifier with the to the physical entity of the chemical product. The physical identifier may correspond to a code, such as a bar code, a QR code, an embossed code, an optical holographic code, such as zero-order diffractive microstructures, or a tag, such as an RFID tag. The physical identifier may be produced by a labelling machine, for example as described in the context of FIG. 12.

In block 1116, the generated digital access element may be provided for access of the digital twin or a part thereof by a decentral data consuming network node, this block being generally optional. The decentral data consuming network node may be part of a decentral network. For instance, the digital access element may be provided to a passport registry accessible by the decentral data consuming network node (see for example FIG. 12). The decentral data consuming network node may use the data contained in the digital access element, such as the decentral access element identifier and the access data, to retrieve the digital twin or a part thereof associated with the decentral access element identifier from a decentral data providing network node, such as digital twin provider 722 as described, for example, in the context of FIG. 15. The digital twin provider 722 may authorize access to the digital twin based on the decentral digital twin identifier associated with the digital access element. Digital twin provider 722 may authorize access to the digital twin based on a decentral participant identifier associated with the decentral data consuming network node requesting access to the digital twin or a part thereof.

The generated digital access element allows a simplified and customizable data sharing or exchange of digital twin data associated with the produced product between participants of the product ecosystem.

FIG. 12 illustrates an example system and associated methods for generating a digital access element associated with a digital twin of a product produced by a production and providing access to the generated digital twin. The product may be a chemical product. The apparatus for generating digital access element(s) of digital twins associated with product(s) may be included in operating system 108 of production 104 (see for example FIG. 1A, FIG. 1B). The production 104 may be a chemical production. The apparatus for generating digital access element(s) of digital twins associated with product(s) may be communicatively coupled to operating system 108 of production 104 (see for example FIG. 1C). The digital twin may be generated as described in the context of FIG. 7A to FIG. 8.

Production 104 may produce at least one product 106 from one or more inbound material(s) 102. The inbound materials may be provided to production 104, for example as described in the context of FIG. 1B and FIG. 1C. The inbound materials may enter the system boundary of production 104 at the entry point, such as a production plant or a material storage associated with production 104. The inbound materials may be used in production 104 to produce one or more product(s) 106 from the inbound materials, for example as described in the context of FIG. 1B to FIG. 2. Operating system 108 of production 104 may monitor and/or control production 104 based on operating parameters of the different processes as described in the context of FIG. 8.

The produced products 106 may be provided at one or more exit points of production 104. The product 106 may exit system boundary 802 of production 104. Upon producing the product 106 or exiting of the product 106 of production 104, the digital access element may be generated. The digital access element(s) may be generated by an apparatus for generating digital access element(s) 1202. The apparatus for generating digital access element(s) 1202 may be configured to generate the digital access element(s). The apparatus 1202 may be configured to receive a request to provide a decentral access element identifier associated with the digital twin. The apparatus 1202 may be configured to generate – in response to the received request – the digital access element(s). In this embodiment, the apparatus 1202 may include an apparatus for generating digital twin(s), such as apparatus 702 described in the context of FIG. 7A and FIG. 7B. In another embodiment (not shown), the apparatus 1202 may be communicatively coupled to an apparatus for generating digital twin(s), such as apparatus 702 described in the context of FIG. 7A and FIG. 7B.

In this embodiment, apparatus 1202 may further include a decentral ID generator 718. In another embodiment (not shown), decentral ID generator 718 may be part of apparatus 702, e.g. apparatus 1202 may not comprise a further decentral ID generator 718. Instead, decentral ID generator 718 of apparatus 702 may be configured to provide the decentral access element identifier (see for example FIG. 7A).

In this embodiment, apparatus 1202 may further include a decentral ID provider 806. In another embodiment (not shown), decentral ID provider 806 may be part of apparatus 702, e.g. apparatus 1202 may not comprise a further decentral ID provider 806. Instead, decentral ID provider 806 of apparatus 702 may be configured to provide the decentral access element identifier (see for example FIG. 7A). While the decentral ID generator 718 and decentral ID provider 806 are shown in FIG. 12 as separate units, their functions may be combined within a single unit such that the apparatus 1202 comprises a decentral ID providing unit configured to perform the functions of decentral ID generator 718 and decentral ID provider 806.

A requestor 1204 may be configured generate the request for the decentral access element identifier. Said request may be triggered by a labelling system such as a QR Code generator. The request may include an owner identifier and/or a product identifier as previously described. The request to provide the decentral access element identifier may be provided to a decentral ID generator 718 configured to provide the decentral access element identifier, for example as described in the context of FIG. 11. Decentral ID generator 718 may be configured to retrieve the decentral digital twin identifier included in the digital twin associated with the chemical product as described in the context of FIG. 11. For instance, decentral ID generator 718 may have access to DT storage 720 and may retrieve the decentral digital twin identifier based on the product identifier contained in the received request. Decentral ID generator 718 may be configured to generate a further decentral identifier. Decentral ID generator 718 may provide the generated further decentral identifier or the retrieved decentral digital twin identifier to a decentral ID provider 806.

Decentral ID provider 806 may provide the retrieved decentral digital twin identifier or the generated further decentral identifier to the requestor 1204. Decentral ID provider 806 may associate the further decentral identifier to the decentral digital twin identifier. The requestor 1204 may be configured to associate the received decentral digital twin identifier/further decentral identifier with the produced product. The requestor 1204 may hence contain an ID assignor configured to assign the decentral digital twin identifier/further decentral identifier to a physical identifier. Such association may include encoding the decentral identifier into a code, such as a bar code, QR code, embossed code, optical holographic code, or a tag, such as an RFID tag, and providing the code or tag for labelling the product. This way a physical identifier may be provided that relates the physical entity of the product with the decentral digital twin identifier/further decentral identifier received from decentral ID provider 806. Since the physical identifier is associated with the product and its virtual digital access element and digital twin, the product can be provided associated with the digital access element which in turn allows access to the digital twin or a part thereof associated with said product. The product associated with the physical identifier may hence be provided physically and the at least one digital access element and digital twin or part thereof associated with the physical identifier may be provided virtually.

Decentral ID provider 806 may provide the decentral digital twin identifier/further decentral identifier to a digital access element generator 1206- configured to generate the digital access element based on the decentral digital twin identifier/further decentral identifier received from decentral ID provider 806 and access data. Digital access element generator 1206 may generate the digital access element as described for example in the context of FIG. 11. The generated digital access element may include the decentral access element decentral identifier and access data. The decentral access element identifier may correspond to or be associated with the decentral digital twin identifier included in the digital twin. This allows to link the digital twin to the digital access element, thus allowing to use the digital access element as a vehicle to convey a digital asset, such as a digital twin or a part thereof, associated with the physical entity of a product to the product consumer. The access data may include digital representation(s) pointing to the digital twin or a part thereof. Said representation may include the endpoint address of the decentral data providing network node associated with the digital twin (i.e. the digital twin provider 722 associated with the respective DT storage 720). Use of the endpoint address of the decentral data providing network node allows to avoid disclosure of the internal endpoint address to the DT storage 720, thus improving the security and avoiding unintended access or leakage of the digital twin or a part thereof. The digital access element may include or be related to one or more authentication mechanisms associated with the decentral access element identifier and/or the access data. The authentication mechanisms may be used as described for example in the context of FIG. 15. The digital access element may relate to one or more authorization mechanisms associated with the decentral access element identifier and/or the access data. The authorization mechanisms may be used as described for example in the context of FIG. 15.

The generated digital access element may be provided to DT storage 720. This allows to store the generated digital access element and hence avoids regeneration of the digital access element.

The generated digital access element may be provided to digital twin provider 722 (not shown). The generated digital access element may be provided to access element registry 1208. Access element registry 1208 may be part of a decentral network 514. Access element registry 1208 may be configured to store digital access element(s) and may serve as a central or decentral repository for existing digital access elements. For instance, access element registry 1208 may store decentral access element identifiers and associated access data. Access element registry 1208 may be available to the public, hence allowing transparency on existing digital access elements and associated digital twins of products. However, access to the digital twins or parts thereof associated with said digital access elements may be controlled by the data owner of the digital access element(s), for example by using a decentral data providing network node implementing appropriate authentication and authorization schemes. This allows to retrain the control of access and use of data with the data owner while at the same time allowing transparency on available digital twins and associated digital twin data set(s).

Decentral data consuming network nodes 808 may have access to access element registry 1208 and may retrieve access data based on the decentral access element identifier, for example as described in the context of FIG. 15. Decentral data consuming network node 808 may be part of a decentral network 514. Decentral data consuming network nodes 808 may be associated with the product consumer, for example as described in the context of FIG. 15. This allows transfer of or access to the digital twin or a part thereof in a controlled and secure manner.

Digital twin provider 722 may be configured to provide the digital twin or a part thereof for access by decentral data consuming network node 808. Digital twin provider 722 may be configured to provide the digital twin or the part thereof based on a decentral digital twin identifier and optionally access data received from decentral data consuming network node 808, for example as described in the context of FIG. 15. Digital twin provider 722 may control the access to the digital twin or the part thereof by decentral data consuming network node 808. Digital twin provider 722 may be a decentral data providing network node associated with production 104. Digital twin provider 722 may be associated with or under control of a data owner of the digital twin. The digital access element may be used to access the digital twin or a part thereof, for example as described in the context of FIG. 15.

The described system and associated method allow to generate digital access elements associated with digital twins of products. The generated digital access elements allow a simplified and customizable data sharing or exchange of digital twin data associated with the produced product between participants of the product ecosystem.

FIG. 13 shows an example of decentral identifier-based owner data 1302, decentral identifier-based digital access element data 1304 and a decentralized identity manager 1306.

The decentral identifier may be a Decentralized Identifier (DID). The decentral identifier-based digital access element may in this case be a DID document 1304 associated with the DID. Besides the DID document 1304 serving as digital access element, FIG. 13 shows a DID owner data element 1302 including decentral identifier-based owner data. Generally, the decentral identifier-based owner data may include the decentral identifier associated with a subject such as digital twin data set(s) and may include one or more authentication mechanism(s). The decentral identifier-based owner data 1302 may include owner data that is electronically owned and controlled by the DID owner. In this context electronically owned may refer to data that is stored in an owner repository or wallet. Such data may be securely stored and/or managed on an organizational server or client device. The decentral identifier-based owner data 1302 may include a DID, a private key and a public key. The DID owner may own and control the DID that represents an identity associated with the DID subject, a private key and public key pair that are associated with the DID. DID may be understood as an identifier and authentication information associated with or uniquely linked to the identifier.

The DID subject may be a raw material, a basic substance, a chemical product, a part, an assembly or an end product. The DID subject may be a machine, a system, or a device used for producing the raw material, the basic substance, the chemical product, the intermediate product, the part, the assembly, or the end product, or a collection of such machine(s), device(s) and/or system(s). The DID owner may be a supply chain participant or a manufacturer such as a chemical manufacturer producing chemicals. The DID owner may be an upstream participant in the supply chain of the chemical manufacturer such as a supplier that supplies raw chemical products or precursors to produce the chemical product. The DID owner may be a downstream participant in the supply chain of the chemical manufacturer such as a customer that consumes chemical products to produce an intermediate product, a component, a component assembly or am end product. The DID owner may be any participant of the supply chain including raw chemical product supplier, intermediate chemical products manufacturer, intermediate part manufacturer, component manufacturer, component assembly manufacturer or end product manufacturer.

The DID may be any identifier that is associated with the DID subject and/or the DID owner. Preferably, the identifier is unique to the DID subject and/or DID owner. The identifier may be unique at least within the scope in which the DID is anticipated to be in use. The identifier may be a locally or globally unique identifier for the raw material, the precursor, the basic substance, the chemical product, the intermediate product, the component, the component assembly, the end product or a collection thereof; the machine, the system, or the device used for producing the raw material, the basic substance, the chemical product, the intermediate product, the component, the component assembly or the end product, or the collection of such machine(s), device(s) and/or system(s); the chemical manufacturer producing chemicals, the upstream participant in the supply chain of the chemical manufacturer, the downstream participant in the supply chain of the chemical manufacturer or a collection thereof; any participant of the supply chain including raw chemical product supplier, intermediate chemical products manufacturer, intermediate part manufacturer, component manufacturer, component assembly manufacturer or end product manufacturer or a collection thereof.

The DID may be any identifier that is associated with the DID subject and the DID owner. Preferably, the DID is unique to the DID subject and/or DID owner. The DID may be unique at least within the scope in which the DID is anticipated to be in use. The DID may be a locally or globally unique identifier for any of the above mentioned possible DID subjects. The DID may also be a Uniform Resource Identifier (URI) such as a Uniform Resource Locator (URL). Moreover, the DID may be an Internationalized Resource Identifier (IRI). The DID may be a Uniform Resource Identifier (URI) such as a Uniform Resource Locator (URL). The DID may be an Internationalized Resource Identifier (IRI). The DID may be a random string of numbers and letters for increased security. In one embodiment, the DID may be a string of 128 letters and numbers e.g. according to the scheme did:method name: method specific-did such as did:example:ebfeb1f712ebc6f1c276e12ec21. The DID may be decentralized ID independent of a centralized, third-party management system and under the control of the DID owner.

The digital access element as DID document 1304 may be associated with the DID, i.e. the DID included in the decentral identifier-based owner data 1302. Accordingly, the digital access element may include a reference to the DID, which is associated with the DID subject that is described by the DID document 1304. The DID document 1304 may also include an authentication information such as the public key. The public key may be used by third-party entities that are given permission by the DID owner/subject to access information and data owned by the DID owner/subject. The public key may also be used for verifying that the DID owner, in fact, owns or controls the DID. The DID document may include authentication information, authorization information e.g. to authorize third party entities to read the DID document or some part of the DID document e.g. without giving the third party the right to prove ownership of the DID.

The digital access element 1304 may include one or more representations that digitally link to the digital twin data set(s), e.g. by way of service endpoints. A service endpoint may include a network address at which a service operates on behalf of the DID owner. In particular, the service endpoints may refer to services, such as decentral data providing network node(s), of the DID owner that give access to the digital twin or a part thereof. Such services may include services to read or analyze product data contained in the digital twin or the part thereof. Product data may include product declaration data, product safety data, certificate of analysis data, emission data, product carbon footprint data, product environmental footprint data, product specification data, product information, technical application data, production data, or combinations thereof.

The digital access element 1304 may include various other information such metadata specifying when the digital access element was created, when it was last modified and/or when it expires.

The DID and digital access element 1304 may be associated with a data registry node such as a centralized data service system or a decentralized data service system 1306, e.g. a distributed ledger or blockchain or a decentralized file system. The distributed ledger or blockchain may be used to store a representation of the DID that points to the digital access element 1304. A representation of the DID may be stored on distributed computing nodes of the distributed ledger or blockchain 1006. For example, DID hash may be stored on multiple computing nodes of the distributed ledger and point to the location of the digital access element 1304. In some embodiments, the digital access element 1304 may be stored on the distributed ledger 1306. Each of the computing nodes may store a copy of the distributed ledger 1306. In this way, each DID hash can be stored redundantly, thereby allowing for an increased data safety. DIDs associated with a plurality of different digital access element 1004 may be included in the distributed ledger 1306.

In some embodiments, the digital access element 1304 may be stored on the distributed ledger 1306, i.e. either additionally or alternatively to the associated DID representation being stored on the distributed

ledger 1306. In other embodiments, the digital access element 1004 may be stored in a data storage (not illustrated) that is associated with the distributed ledger or blockchain or decentralized file system.

The distributed ledger or blockchain 1306 may be any decentralized, distributed network that includes various computing nodes that are in communication with each other. For example, the distributed ledger 1306 may include a first distributed computing node, a second distributed computing node, a third distributed computing node, and any number of additional distributed computing nodes (not shown). The distributed ledger or blockchain 1306 may include known technology stacks like Bitcoin (see e.g. Bitcoin documentation of November 11, 2022 published https://en.bitcoin.it/wiki/Protocol_documentation), Ethereum (see e.g. Ethereum documentation of August 15, 2022 published on https://ethereum.org/en/developers/docs/), Solana (see e.g. Solana documentation of November 11, 2022 published on https://spl.solana.com/), Polygon (see e.g. Polygon documentation of November 11, 2022 published on https://wiki.polygon.technology/) or other implementations with varying degree of data transactions performed on the distributed ledger. The description of the example framework is only for illustrative purposes and shall not be considered limiting.

FIG. 14A illustrates a first example of a linkage between the data sets of a digital twin and a digital access element via the decentral digital twin identifier. The digital twin 1402 may be generated as described in the context of FIG. 7A to FIG. 8 using a digital twin template. Digital twin 1402 may be stored in DT storage 720. Digital access element 1410 associated with the physical entity of the product may be generated as described in FIG. 11 and FIG. 12. Data sets 1404, 1406 associated with digital twin 1402 are each assigned to decentral digital twin identifier 1408. Use of said decentral digital twin identifier 1408 hence allows to identify all existing data sets contained in digital twin 1402. The decentral digital twin identifier 1408 may include further identifiers, such as data set identifiers of data sets 1404, 1406. This allows to uniquely identify the data sets contained in the digital twin using the decentral digital twin identifier 1408 and the respective data set identifier.

Digital access element 1410 may contain a decentral passport identifier 1412. Decentral passport identifier 1412 may be a decentral identifier linked to the decentral digital twin identifier 1408 included in the digital twin. Decentral passport identifier 1412 may correspond to the decentral digital twin identifier 1408 included in digital twin 1402. The latter avoids generation of a new decentral identifier and linking of the newly generated decentral identifier to the decentral digital twin identifier included in the digital twin.

The digital access element may further contain access data 1414. Access data 1414 may include digital representation(s) pointing directly or indirectly to the storage structure storing the digital twin or a part thereof (e.g. data sets 1404, 1406), such as DT storage 720 (not shown). Access data 1414 may include a digital representation pointing to the decentral data providing network node associated with DT storage 720 (not shown).

Digital access element 1410 may be linked via the decentral passport identifier 1412 to digital twin 1402 and hence also to the data sets contained in the digital twin, thus allowing to retrieve the digital twin or a part thereof (e.g. the data set 1404, 1406) using the decentral passport identifier 1412 and access data 1414 included in digital access element 1410 as described in the context of FIG. 15.

FIG. 14B illustrates a second example of a linkage between digital twin 1402, associated data sets 1404, 1406 and digital access elements 1416, 1422 via the decentral digital twin identifier 1408 and decentral passport identifiers 1420, 1426. Digital twin 1402 may be generated as described in in the context of FIG. 7A to FIG. 8 using a digital twin template. The digital access elements 1416, 1422 associated with the physical entity of the product may be generated as described in FIG. 11 and FIG. 12. The data sets 1404, 1406 associated with digital twin 1402 are assigned to the decentral digital twin identifier 1408. Use of said decentral digital twin identifier 1408 thus allows to identify all existing data sets contained in digital twin 1402.

In this example, a first digital access element 1416 may be generated for data set 1 1404 and a second digital access element 1422 may be generated for data set 2 1406. Digital access elements may be generated for each data set or for at least part of the data sets contained in a digital twin. Each digital access element may be linked by the decentral passport identifier 1420, 1426 via the decentral digital twin identifier 1408 to the respective data set. Each digital access element 1416, 1422 may contain access data 1414, 1424. Said access data 1414, 1424 may include a digital representation pointing to the product data set as described in the context of FIG. 14A.

FIG. 14A and FIG. 14B only show two example embodiments and any number of digital access elements and any number of data sets within the digital twin may be possible. For instance, a first digital access element may be generated for a first number of data sets while a second digital access element may be generated for a second number of data sets. The number of data sets may include one or more data sets.

FIG. 15 shows a schematic illustration of providing access by a decentral data providing network node to a digital twin or a part thereof associated with a product using a digital access element. Access to the digital twin or the part thereof may be requested by a decentral data consuming network node. The product 106 may be produced by production 104, such as a chemical production described in the context of FIG. 1A to FIG. 2. The digital twin may include the decentral digital twin identifier and at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product.

A digital access element may be generated upon or after production of the product, for example as described in the context of FIG. 11 and FIG. 12. The digital access element may be associated with the digital twin or the part thereof. The digital access element may contain a decentral access element identifier and access data. The decentral access element identifier may correspond to or be associated with the decentral digital twin identifier of the digital twin. The access data may include digital

representation(s) pointing to the digital twin or parts thereof. The access data may include digital twin data identifier(s) associated with digital twin data set(s) contained in the digital twin (see for example FIG. 13). An example of a digital access element is illustrated in FIG. 13. The digital access element may further include or relate to authentication and/or authorization information linked to the decentral access element identifier. The authentication and/or authorization information may be provided for authentication and/or authorization of digital twin provider 722 and/or the decentral data consuming network node 808. The digital access element may be provided to access element registry 1208 for example as described in the context of FIG. 12. Access element registry 1208 may store decentral access element identifier(s) and associated access data.

The product 106 as produced by production 104 may be provided in association with the digital access element to a consumer. The consumer may process the product to produce further chemical and/or discrete products. The product 106 may be connected to a code, such as a bar code or QR-code, having encoded the decentral passport identifier. The consumer of the product 106 may read the code through a code reader 1502. The code reader 1502 may be a smartphone running a code reading application, such as a QR code reader app. The data obtained by the code reading application may be used to determine the decentral access element identifier. The data obtained by the code reading application may be used to determine the decentral digital twin identifier. The data obtained by the code reading application may be used to determine the product identifier. The data obtained by the code reading application may be used to determine the access data. The decentral access element identifier, decentral digital twin identifier, product identifier and access data may be determined by code reader 1502. For instance, the decentral passport identifier may be determined by the code reader 1502 may be a DID and the code reader 1502 may be configured to retrieve the associated DID document containing the decentral digital twin identifier and the access data, for example using a DID resolver (see also FIG. 13). In another instance, the product identifier may be determined by code reader 1502 and used to retrieve the decentral access element identifier and associated access data, for example from a database, such as access element registry 1208. Hence, code reader 1502 may be configured to retrieve the digital access element containing the decentral access element identifier and access data from access element registry 1208. Code reader 1502 may be configured to provide the decentral access element identifier and/or the decentral digital twin identifier to a database 1506 associated with the consumer of the product. Code reader 1502 may be configured to provide the determined decentral access element identifier, decentral digital twin identifier and access data to decentral data consuming network node 808.

Code reader 1502 may be configured to display determined/retrieved data on a user interface as illustrated by reference sign 1504. The user interface may display the determined decentral access element identifier (PP identifier), the determined decentral digital twin identifier (DT identifier) and the determined access data (DT location). In this embodiment, the decentral access element identifier and the decentral digital twin identifier differ from each other. In another embodiment, the decentral access element identifier is equal to the decentral digital twin identifier. The user interface may further display

the determined product identifier (CP identifier). The user interface may also allow to initiate retrieval of the digital twin or a part thereof based on the decentral access element identifier and the access data as described in the following. This process may be initiated by the button denoted “Access DT”. Upon pressing said button, code reader 1502 may send a request to access the digital twin or the part thereof to decentral data consuming network node 808.

Decentral data consuming network node 808 associated with the consumer of the product may generate a request to access the digital twin or a part thereof. Decentral data consuming network node 808 may generate the request based on the data received from code reader 1502. For instance, decentral data consuming network node 808 may generate the request based on the decentral digital twin identifier received from code reader 1502. Decentral data consuming network node 808 may generate the request based on the decentral access element identifier and/or decentral digital twin identifier provided to database 1506. For example, decentral data consuming network node 808 may be configured to retrieve the decentral digital twin identifier and access data from access element registry 1208 based on the decentral access element identifier stored in database 1506. The request generated by decentral data consuming network node 808 may include the decentral digital twin identifier and a decentral participant identifier associated with a participant of the decentral network operating decentral data consuming network node 808. Decentral data consuming network node 808 may be configured to determine digital twin provider 722 associated with the digital twin based on the access data provided by code reader 1502 or provided from access element registry 1208.

Decentral data consuming network node 808 may sent the request to access the digital twin or a part thereof to the determined digital twin provider 722 as signified by arrow 1508. Digital twin provider 722 may be associated with the product producer. Digital twin provider 722 may be associated with production 104, such as a chemical production, producing the product 106. Digital twin provider 722 may be associated with the data owner of the digital twin. In addition to the request, authentication and/or authorization information may be provided by decentral data consuming network node 808.

The request may be authenticated. The request may be validated by digital twin provider 722, for example by retrieving access rules from a database of digital twin provider 722 based on the decentral digital twin identifier contained in the received request. At least part of the retrieved access rules may be applied to the received request. This allows to filter decentral data consuming network nodes requesting access based on the decentral participant identifier(s) associated with participant of the decentral network operating said network nodes. If the request is not valid, e.g. if the decentral data consuming network node is not authorized to access the digital twin data, the peer-to-peer communication channel will be terminated by digital twin provider 722 and no digital twin will be provided.

If the request is valid, digital twin provider 722 may initiate contract negotiations with decentral data consuming network node 808. Digital twin provider 722 may provide an electronic contract to decentral

data consuming network node 808. The electronic contract may include access rule(s) associated with the decentral digital twin identifier. This allows the data consumer to determine access and usage conditions associated with the desired data. Digital twin provider 722 and decentral data consuming network node 808 may be configured to negotiate an electronic contract and to sign the negotiated electronic contract. Use of the electronic contract ensures that decentral data consuming network node 808 and further systems handling the digital twin or a part thereof are complying to access rule(s) associated with the digital twin. Upon signature of the electronic contract, digital twin provider 722 may retrieve or request the digital twin stored in DT storage 720 based on the decentral digital twin identifier contained in the received request as designated by arrows 1510 and 1512. Digital twin provider 722 may apply determined access rule(s) to the retrieved or received digital twin. Afterwards digital twin provider 722 may provide the digital twin or parts thereof according to the applied access rule(s) to the decentral data consuming network node 808 as signified by arrow 1514.

The digital twin provided by digital twin provider 722 may be stored in database 1506 associated with decentral data consuming network node 808 according to the access rule(s) as signified by arrow 1516.

Through the decentral digital twin identifier, the digital twin can be uniquely associated with the product. Through the decentral network, the digital twin or a part thereof may be transferred between the producer of the product and the consumer of the product in a standardized and secure way, allowing the producer of the product to control access to the digital twin or the part thereof by multiple decentral data consuming network nodes existing within the decentral network. This way, the digital twin or the part thereof can be shared with unique association to the product and without central intermediary directly between the participants of the product ecosystem. This allows for transparency of digital twins within the product ecosystem.

The generation of a digital twin of a physical entity of a produced product as well as the generation of a digital access element associated with said digital twin allows to share product data set contained in the digital twin under simplified and customizable conditions without compromising data security and data sovereignty.

The present disclosure has been described in conjunction with preferred embodiments and examples as well. However, other variations can be understood and effected by those persons skilled in the art and practicing the claimed invention, from the studies of the drawings, this disclosure and the claims.

Any steps presented herein can be performed in any order. The methods disclosed herein are not limited to a specific order of these steps. It is also not required that the different steps are performed at a certain place or in a certain computing node of a distributed system, i.e. each of the steps may be performed at different computing node using different equipment/data processing.

As used herein „determining“ also includes „initiating or causing to determine“, “generating“ also includes „initiating and/or causing to generate“ and “providing” also includes “initiating or causing to determine, generate, select, send and/or receive”. “Initiating or causing to perform an action” includes any processing signal that triggers a computing node or device to perform the respective action.

In the claims as well as in the description the word “comprising” does not exclude other elements or steps and the indefinite article “a” or “an” does not exclude a plurality. A single element or other unit may fulfill the functions of several entities or items recited in the claims. The mere fact that certain measures are recited in the mutual different dependent claims does not indicate that a combination of these measures cannot be used in an advantageous implementation.

CLAIMS

1. An apparatus for generating a digital twin template associated with a product or a product class, wherein the digital twin template defines one or more aspect models, each aspect model describing a specific set of properties of the product or the product class, the apparatus comprising one or more computing node, and one or more computer-readable media having thereon computer-executable instructions which, when executed by the one or more computing node, configure the apparatus to perform the steps of:
   - receiving a request to generate the digital twin template, the request including data related to the product,
   - providing a digital twin master template associated with one or more product classes, wherein the digital twin master template defines a plurality of aspect models,
   - providing product data based on the data contained in the received request,
   - optionally providing one or more further aspect model(s), wherein the one or more further aspect model(s) are different from the plurality of aspect models defined in the digital twin master template,
   - generating - based on the provided product data - the digital twin template defining at least one aspect model defined in the digital twin master template and optionally at least one of the provided further aspect models.

2. The apparatus of claim 1, wherein the data related to the product includes a product identifier, a product class or a combination thereof.

3. The apparatus of claim 1 or 2, wherein the digital twin master template includes the plurality of aspect models and/or includes one or more digital representations pointing to the plurality of aspect models.

4. The apparatus of any one of claims 1 to 3, wherein the digital twin master template defines relationships between one or more aspect models of the plurality of aspect models defined in said master template.

5. The apparatus of any one of claims 1 to 4, wherein the plurality of aspect models includes at least one mandatory aspect model and optionally at least one non-mandatory aspect model.

6. The apparatus of claim 5, wherein the at least one mandatory aspect model includes aspect model(s) defining digital twin data, aspect model(s) defining digital twin template data, aspect model(s) defining product safety data, aspect model(s) defining the product producer, aspect model(s) defining the identification of the product, aspect model(s) defining at least a part of the composition of the product, aspect model(s) defining product parameters, aspect model(s) defining the handling of the product, aspect model(s) defining the disposal of the product, or a combination thereof.

7. The apparatus of claim 5 or 6, wherein non-mandatory aspect models include aspect model(s) defining product packaging data, aspect model(s) defining certificate of analysis data associated with the product, aspect model(s) defining emission data associated with the product, aspect model(s) defining production data associated with the product, aspect model(s) defining technical data associated with the product, aspect model(s) defining certificate data associated with the product, aspect model(s) defining data on the supplier of materials used to produce the product, aspect model(s) defining data on the supply of the product to a consumer of the product, aspect model(s) defining data on the registration of the product, or a combination thereof.

8. The apparatus of any one of claims 1 to 7, wherein generating the digital twin template includes selecting at least one aspect model from the plurality of aspect models defined in the provided digital twin master template and optionally selecting at least one of the provided further aspect models based on the provided product data.

9. The apparatus of any one of claims 1 to 8, wherein the digital twin template includes at least one of the aspect models defined in the digital twin master template and optionally at least one of the provided further aspect models and/or includes one or more digital representations defined in the digital twin master template and optionally one or more digital representations pointing to at least one of the provided further aspect models.

10. A computer-implemented method for generating a digital twin template associated with a product or a product class, wherein the digital twin template defines one or more aspect models, each aspect model describing a specific set of properties of the product or the product class, the method comprising the steps of:
    - receiving a request to generate the digital twin template, the request including data related to the product,
    - providing a digital twin master template associated with one or more product classes, wherein the digital twin master template defines a plurality of aspect models,
    - providing product data based on the data contained in the received request,
    - optionally providing one or more further aspect model(s), wherein the one or more further aspect model(s) are different from the plurality of aspect models defined in the digital twin master template,
    - generating - based on the provided product data - the digital twin template defining at least one aspect model defined in the digital twin master template and optionally at least one of the provided further aspect models.

11. Digital twin template as generated by the apparatus of any one of claims 1 to 9 or by the computer-implemented method of claim 10.

12. Use of the digital twin template according to claim 11 for generating a digital twin of a physical entity of a product.

13. An apparatus for generating a digital twin of a physical entity of a product, the apparatus comprising: one or more computing node; and one or more computer-readable media having thereon computer-executable instructions which, when executed by the one or more computing node, configure the apparatus to perform the steps of:
    - receiving a request to generate the digital twin, the request including data related to the product,
    - gathering data associated with the product from one or more data sources based on the received data related to the product, wherein the data associated with the product includes at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product,
    - providing a decentral digital twin identifier associated with the gathered data and optionally a data owner,
    - providing a digital twin template to be applied to the gathered product data based on the data included in the received request, wherein the digital twin template has been generated by the apparatus of any one of claims 1 to 9 or according to the computer-implemented method of claim 10,
    - generating - for each aspect model defined in the provided digital twin template - a digital twin data set by applying the respective aspect model to the gathered data,
    - generating the digital twin including the provided decentral identifier and the generated digital twin data sets.

14. A computer-implemented method for generating a digital twin of a physical entity of a product, the method comprising the steps of:
    - receiving a request to generate the digital twin, the request including data related to the product,
    - gathering data associated with the product from one or more data sources based on the received data related to the product, wherein the data associated with the product includes at least one measured physical and/or chemical property of the product and/or at least one physical and/or chemical property determined from collected data associated with the production and/or the use of the product,
    - providing a decentral digital twin identifier associated with the gathered data and optionally a data owner,
    - providing a digital twin template to be applied to the gathered product data based on the data included in the received request, wherein the digital twin template has been generated by the

apparatus of any one of claims 1 to 9 or according to the computer-implemented method of claim 10,

- generating - for each aspect model defined in the providing digital twin template - a digital twin data set by applying the respective aspect model to the gathered data,
- generating the digital twin including the provided decentral identifier and the generated digital twin data sets.

15. A computer element, such as a computer readable storage medium, a computer program or a computer program product, comprising instructions, which when executed by a computing node or a computing system, direct the computing node or computing system to carry out the steps of the methods of claim 10 and/or claim 14.

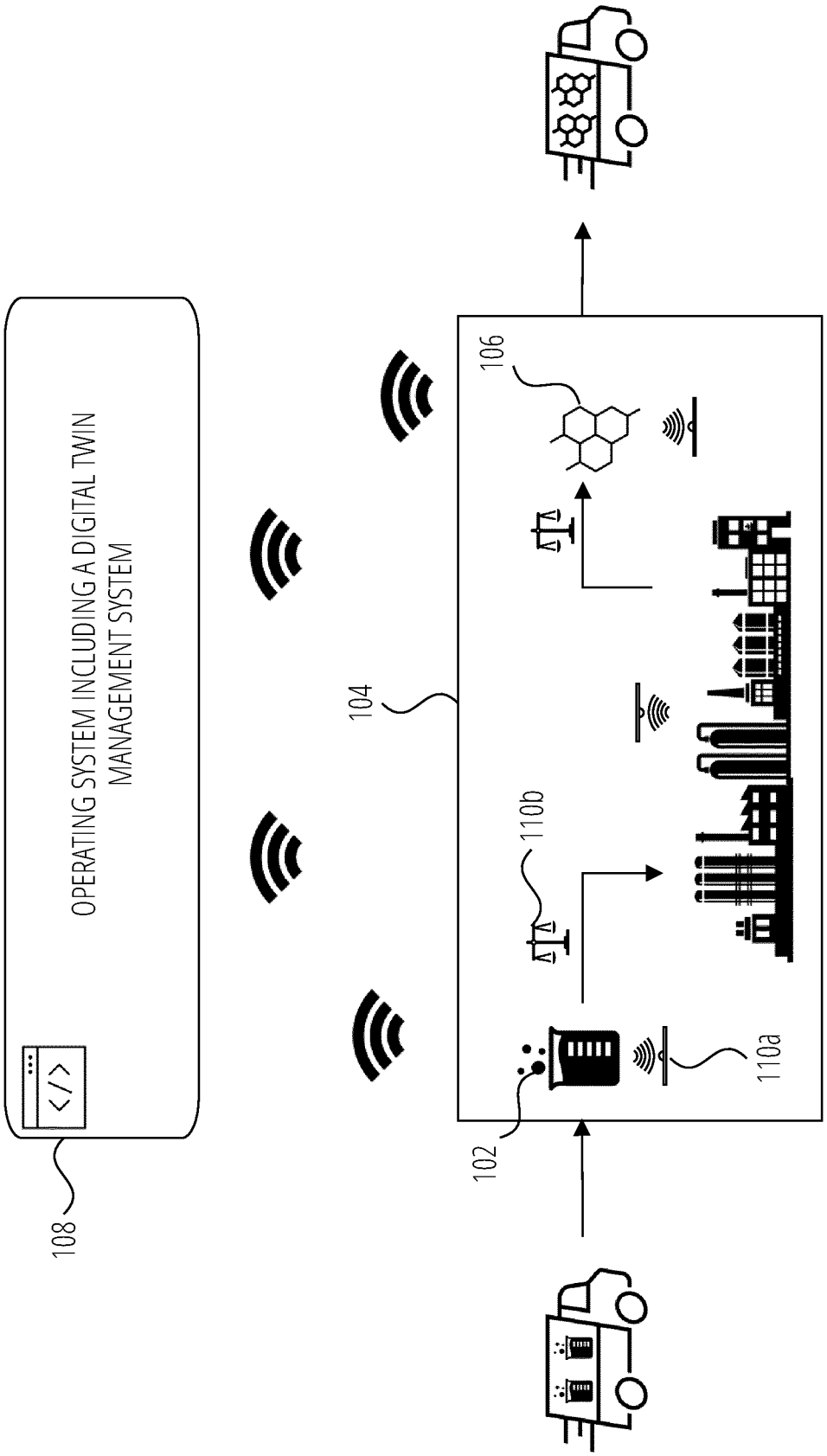
OPERATING SYSTEM INCLUDING A DIGITAL TWIN MANAGEMENT SYSTEM
108
102
104
106
110a
110b

FIG. 1A

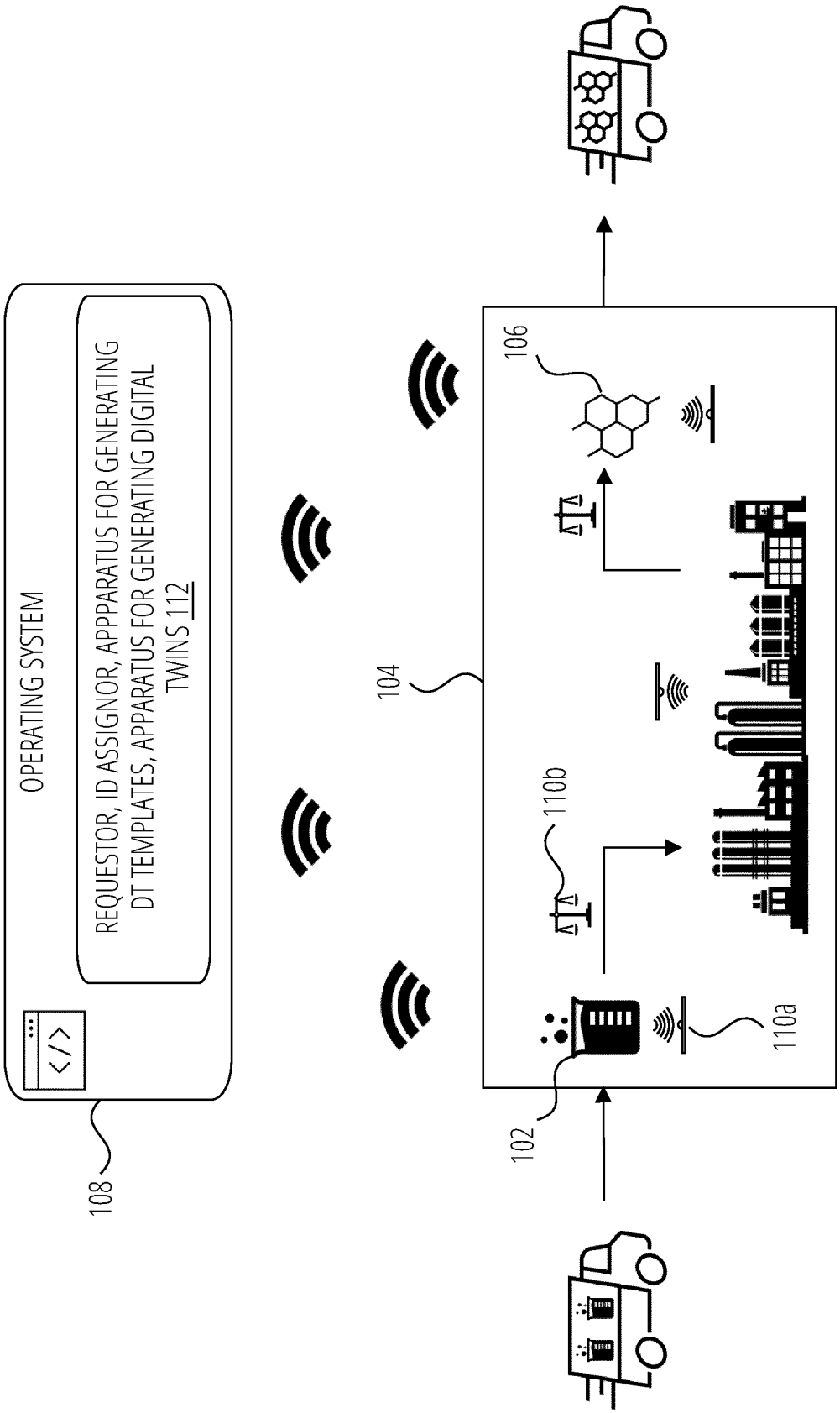
OPERATING SYSTEM
REQUESTOR, ID ASSIGNOR, APPPARATUS FOR GENERATING DT TEMPLATES, APPARATUS FOR GENERATING DIGITAL TWINS 112
108
102
104
106
110a
110b

FIG. 1B

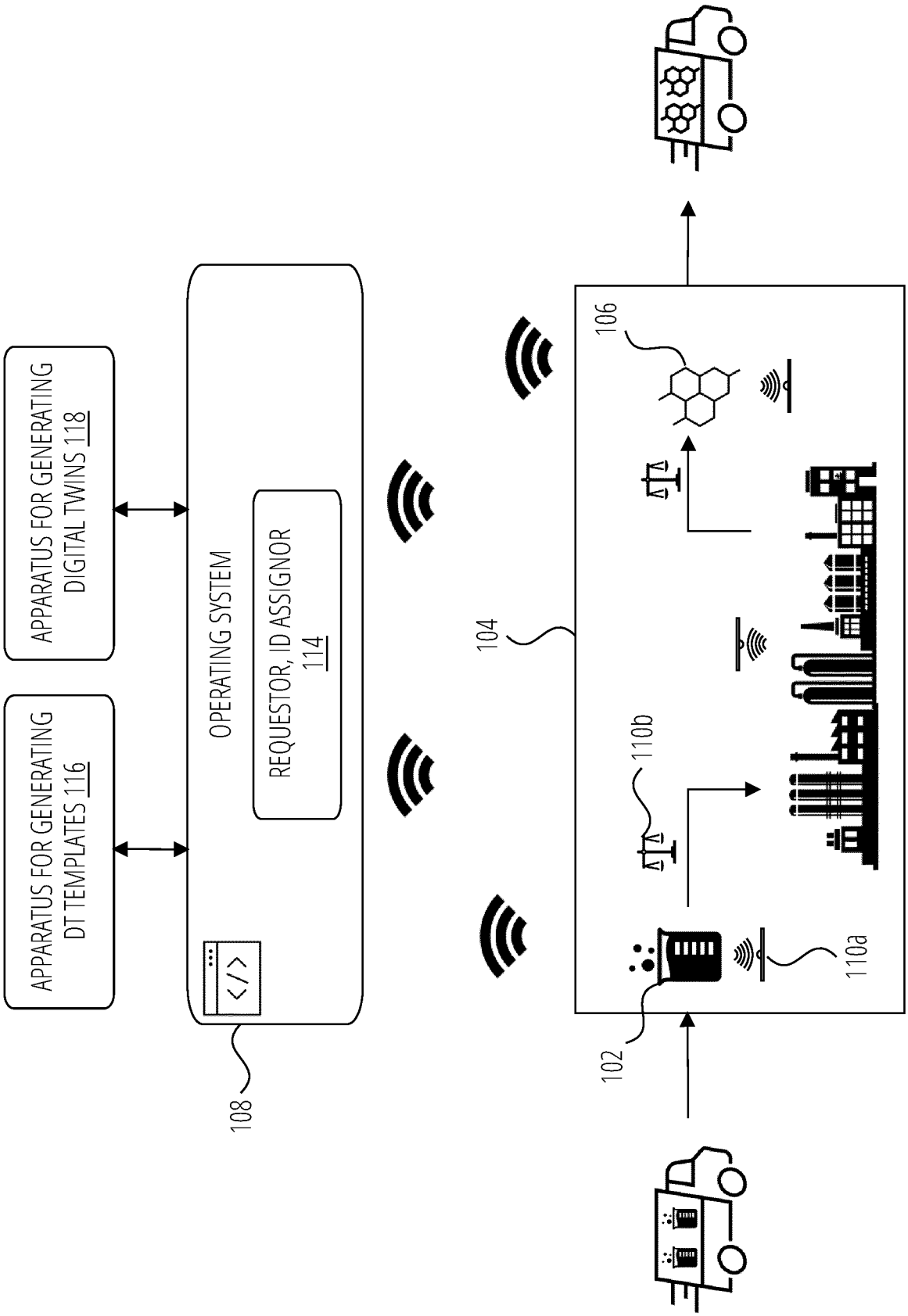
APPARATUS FOR GENERATING DIGITAL TWINS 118
APPARATUS FOR GENERATING DT TEMPLATES 116
OPERATING SYSTEM
REQUESTOR, ID ASSIGNOR 114
108
104
106
110b
110a
102

FIG. 1C

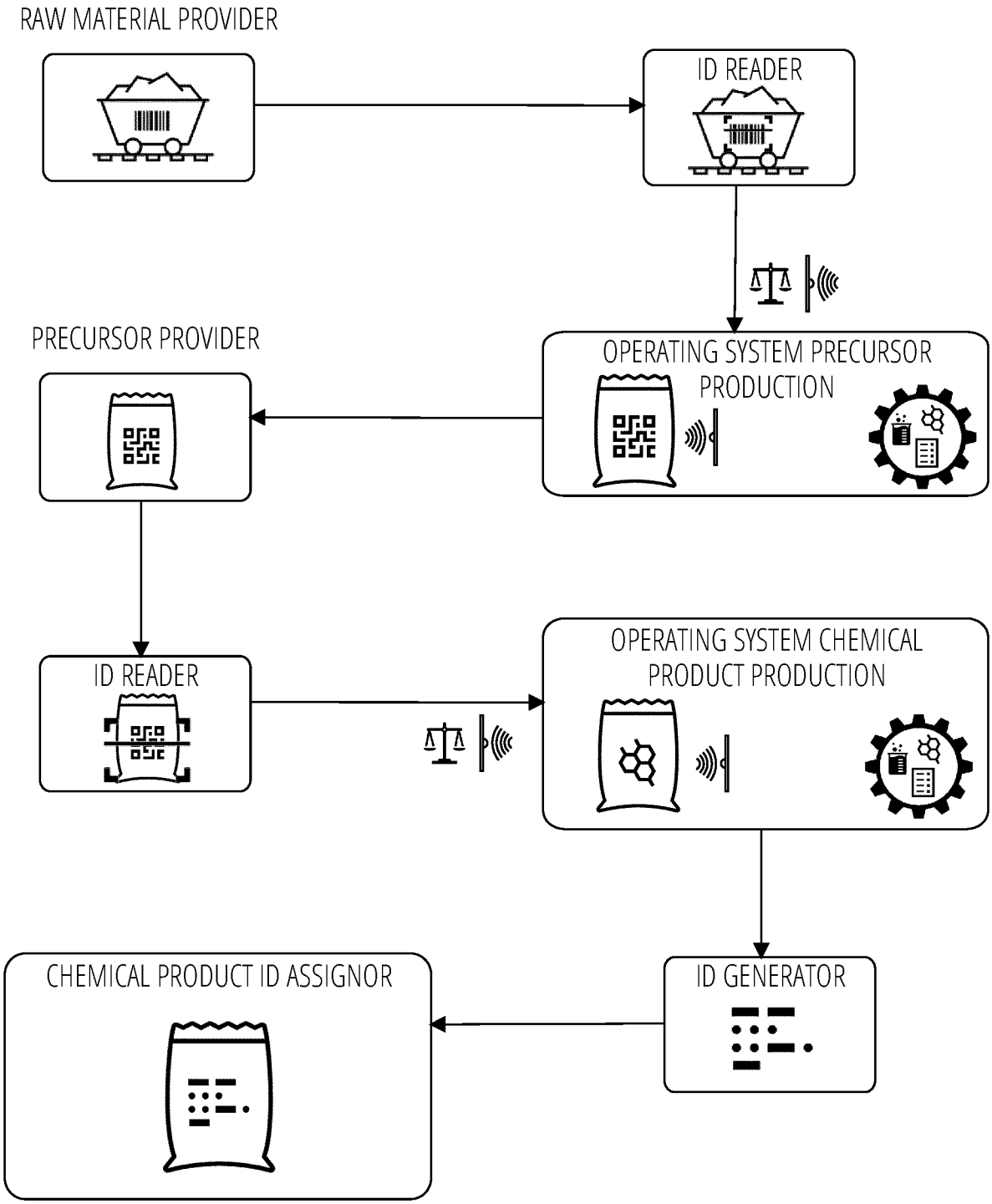
RAW MATERIAL PROVIDER
ID READER
PRECURSOR PROVIDER
OPERATING SYSTEM PRECURSOR PRODUCTION
ID READER
OPERATING SYSTEM CHEMICAL PRODUCT PRODUCTION
CHEMICAL PRODUCT ID ASSIGNOR
ID GENERATOR

FIG. 2

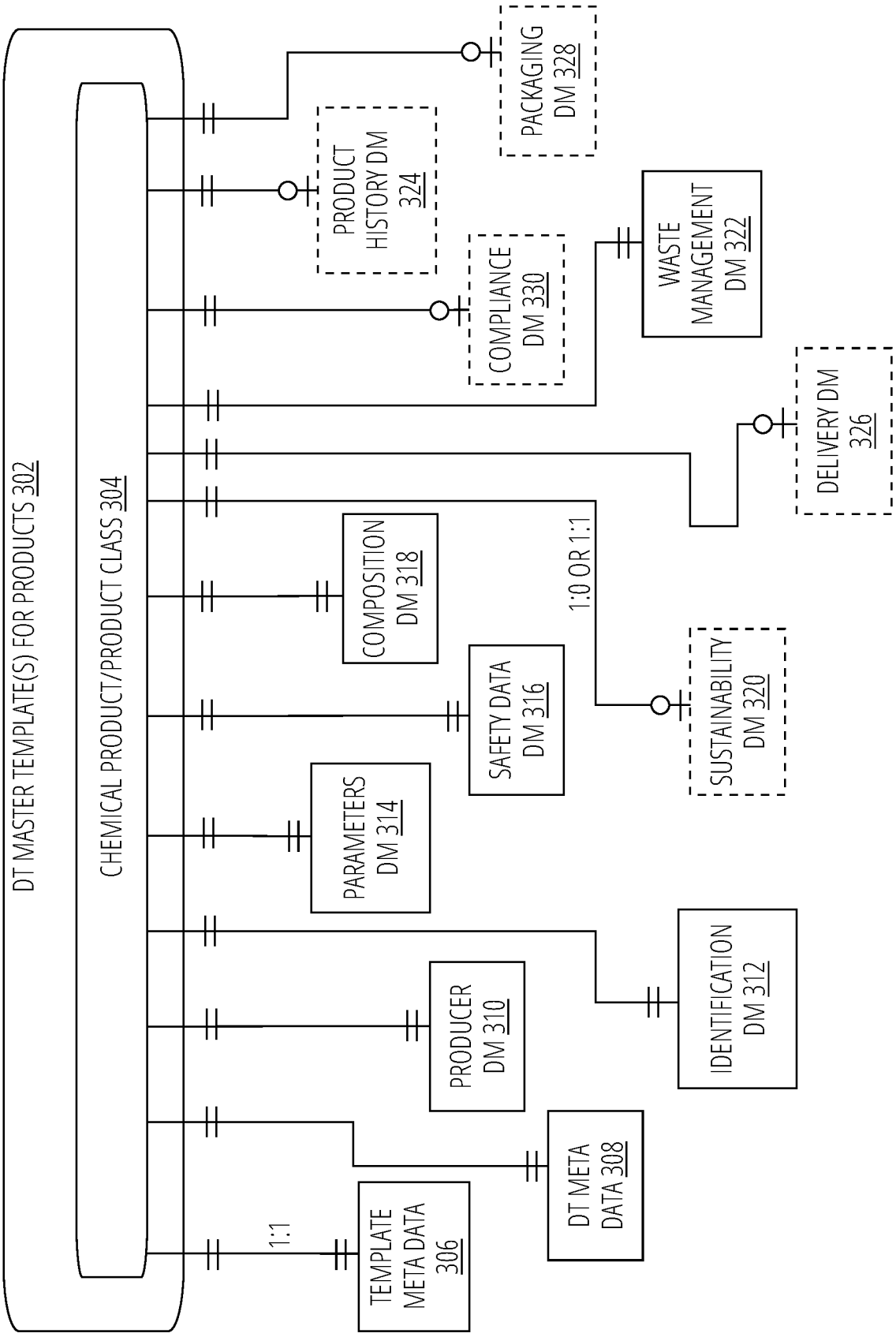
DT MASTER TEMPLATE(S) FOR PRODUCTS 302
CHEMICAL PRODUCT/PRODUCT CLASS 304
1:1
TEMPLATE META DATA 306
DT META DATA 308
PRODUCER DM 310
IDENTIFICATION DM 312
PARAMETERS DM 314
SAFETY DATA DM 316
COMPOSITION DM 318
1:0 OR 1:1
SUSTAINABILITY DM 320
DELIVERY DM 326
COMPLIANCE DM 330
WASTE MANAGEMENT DM 322
PRODUCT HISTORY DM 324
PACKAGING DM 328

FIG. 3A

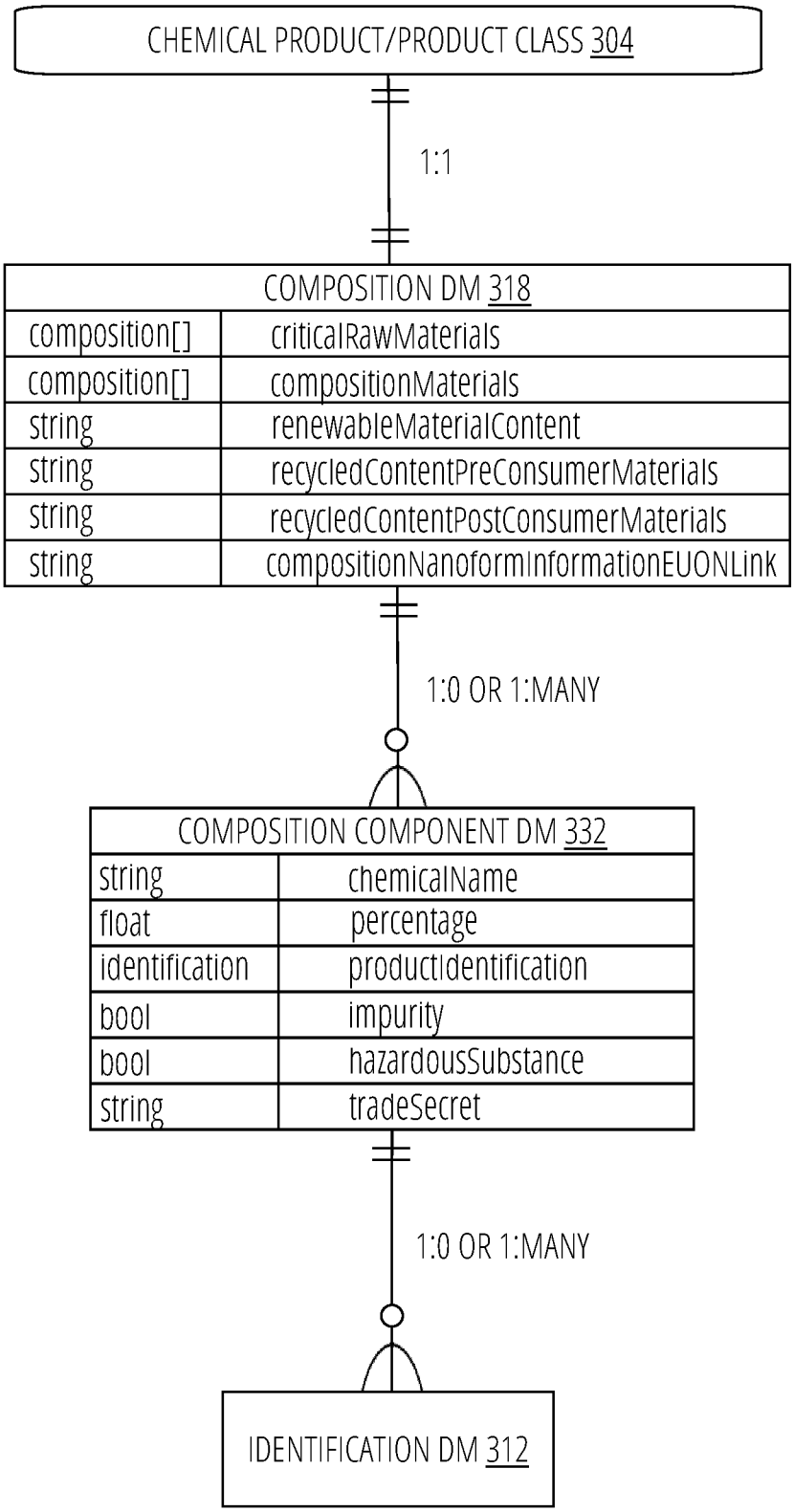
CHEMICAL PRODUCT/PRODUCT CLASS 304
1:1
COMPOSITION DM 318
composition[] criticalRawMaterials
composition[] compositionMaterials
string renewableMaterialContent
string recycledContentPreConsumerMaterials
string recycledContentPostConsumerMaterials
string compositionNanoformInformationEUONLink
1:0 OR 1:MANY
COMPOSITION COMPONENT DM 332
string chemicalName
float percentage
identification productIdentification
bool impurity
bool hazardousSubstance
string tradeSecret
1:0 OR 1:MANY
IDENTIFICATION DM 312

FIG. 3B

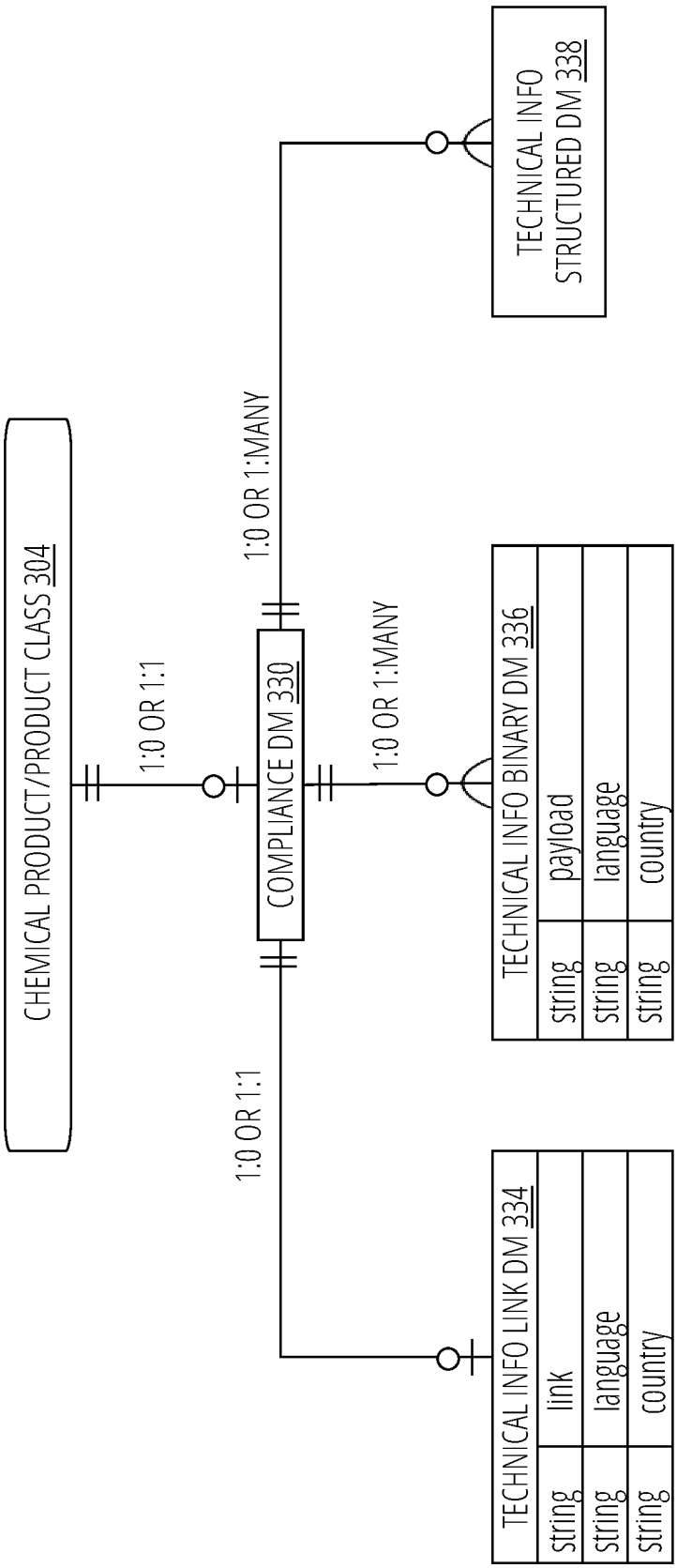
CHEMICAL PRODUCT/PRODUCT CLASS 304
1:0 OR 1:1
COMPLIANCE DM 330
1:0 OR 1:MANY
TECHNICAL INFO STRUCTURED DM 338
1:0 OR 1:MANY
TECHNICAL INFO BINARY DM 336
string payload
string language
string country
1:0 OR 1:1
TECHNICAL INFO LINK DM 334
string link
string language
string country

FIG. 3C

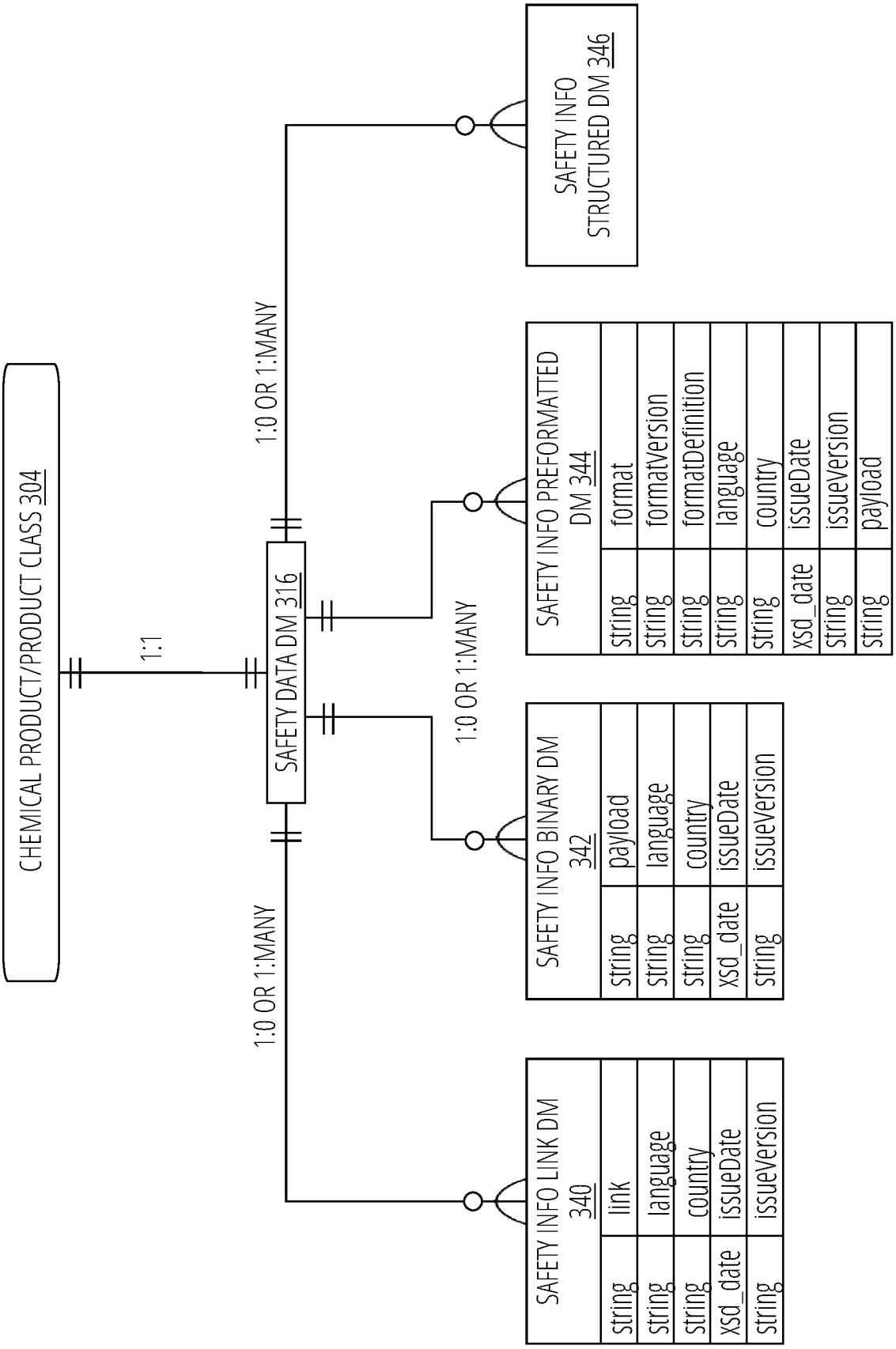
CHEMICAL PRODUCT/PRODUCT CLASS 304
1:1
SAFETY DATA DM 316
1:0 OR 1:MANY
1:0 OR 1:MANY
1:0 OR 1:MANY
SAFETY INFO STRUCTURED DM 346
SAFETY INFO PREFORMATTED DM 344
string format
string formatVersion
string formatDefinition
string language
string country
xsd_date issueDate
string issueVersion
string payload
SAFETY INFO BINARY DM 342
string payload
string language
string country
xsd_date issueDate
string issueversion
SAFETY INFO LINK DM 340
string link
string language
string country
xsd_date issueDate
string issueversion

FIG. 3D

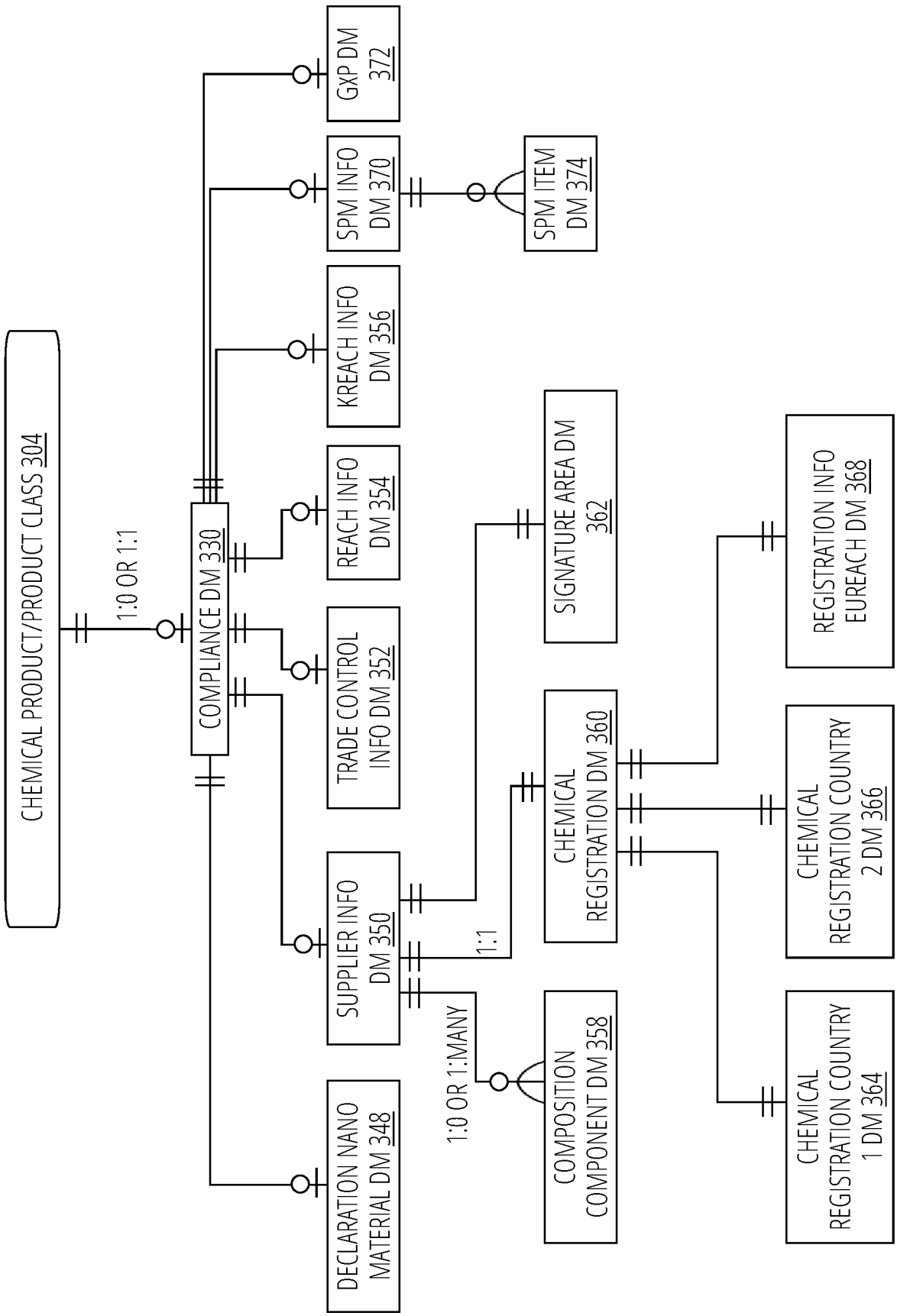
CHEMICAL PRODUCT/PRODUCT CLASS 304
1:0 OR 1:1
COMPLIANCE DM 330
GXP DM 372
SPM INFO DM 370
SPM ITEM DM 374
KREACH INFO DM 356
REACH INFO DM 354
TRADE CONTROL INFO DM 352
SIGNATURE AREA DM 362
SUPPLIER INFO DM 350
1:1
CHEMICAL REGISTRATION DM 360
REGISTRATION INFO EUREACH DM 368
1:0 OR 1:MANY
COMPOSITION COMPONENT DM 358
CHEMICAL REGISTRATION COUNTRY 2 DM 366
DECLARATION NANO MATERIAL DM 348
CHEMICAL REGISTRATION COUNTRY 1 DM 364

FIG. 3E

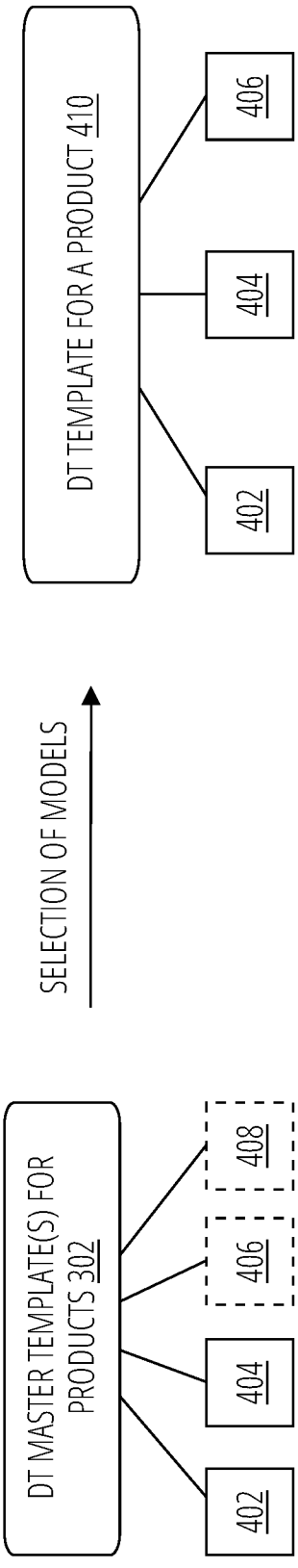
DT MASTER TEMPLATE(S) FOR PRODUCTS 302
402
404
406
408
SELECTION OF MODELS
DT TEMPLATE FOR A PRODUCT 410
402
404
406

FIG. 4A

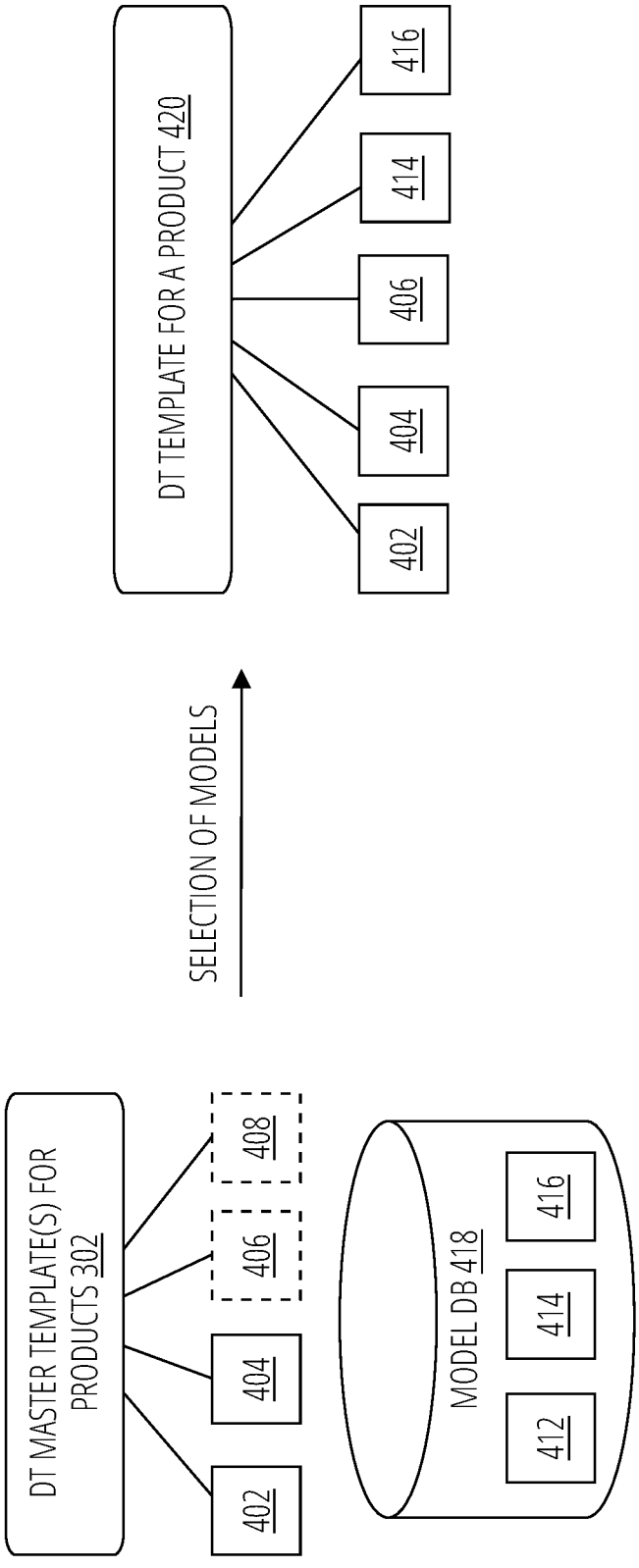
DT MASTER TEMPLATE(S) FOR PRODUCTS 302
402
404
406
408
MODEL DB 418
412
414
416
SELECTION OF MODELS
DT TEMPLATE FOR A PRODUCT 420
402
404
406
414
416

FIG. 4B

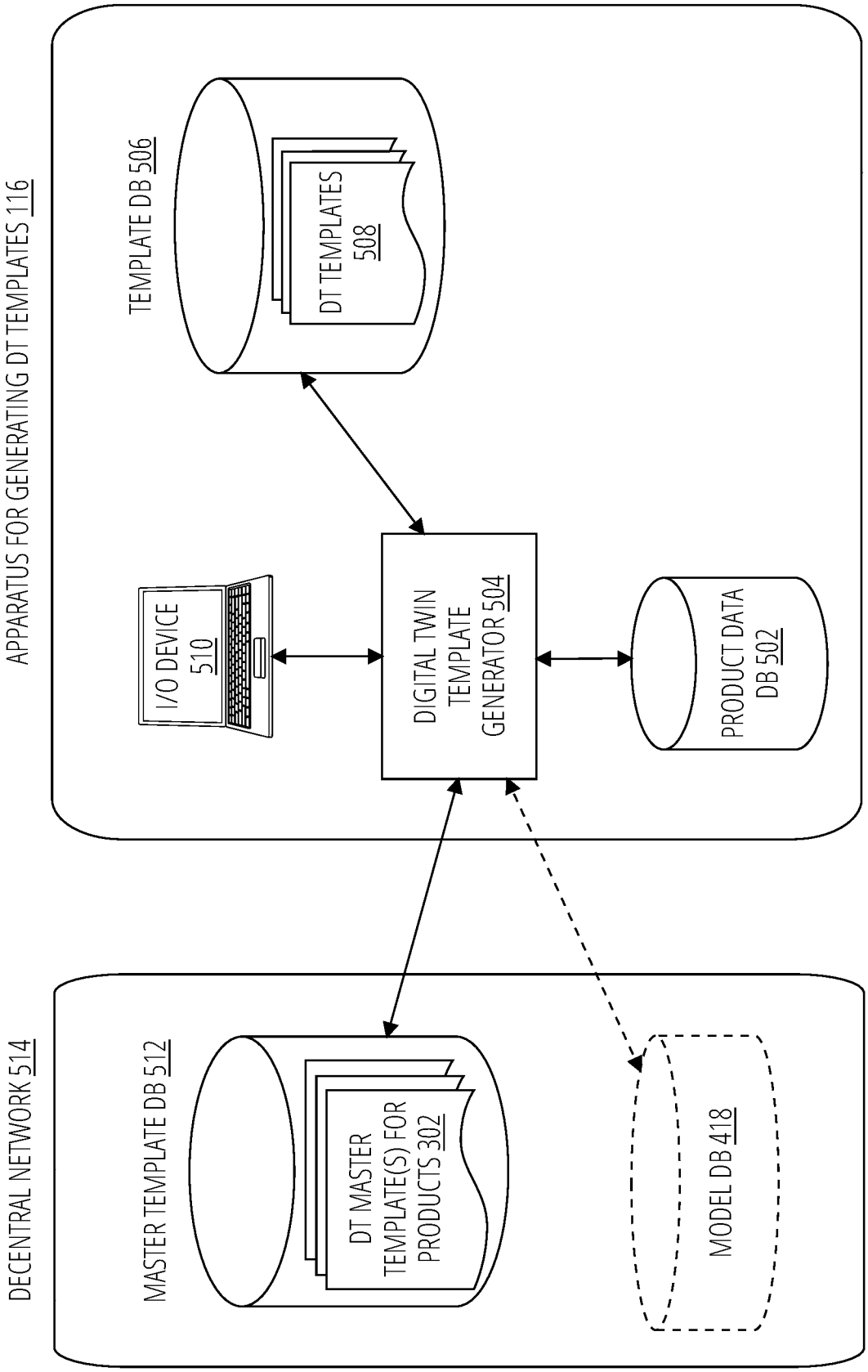
APPARATUS FOR GENERATING DT TEMPLATES 116
TEMPLATE DB 506
DT TEMPLATES 508
I/O DEVICE 510
DIGITAL TWIN TEMPLATE GENERATOR 504
PRODUCT DATA DB 502
DECENTRAL NETWORK 514
MASTER TEMPLATE DB 512
DT MASTER TEMPLATE(S) FOR PRODUCTS 302
MODEL DB 418

FIG. 5

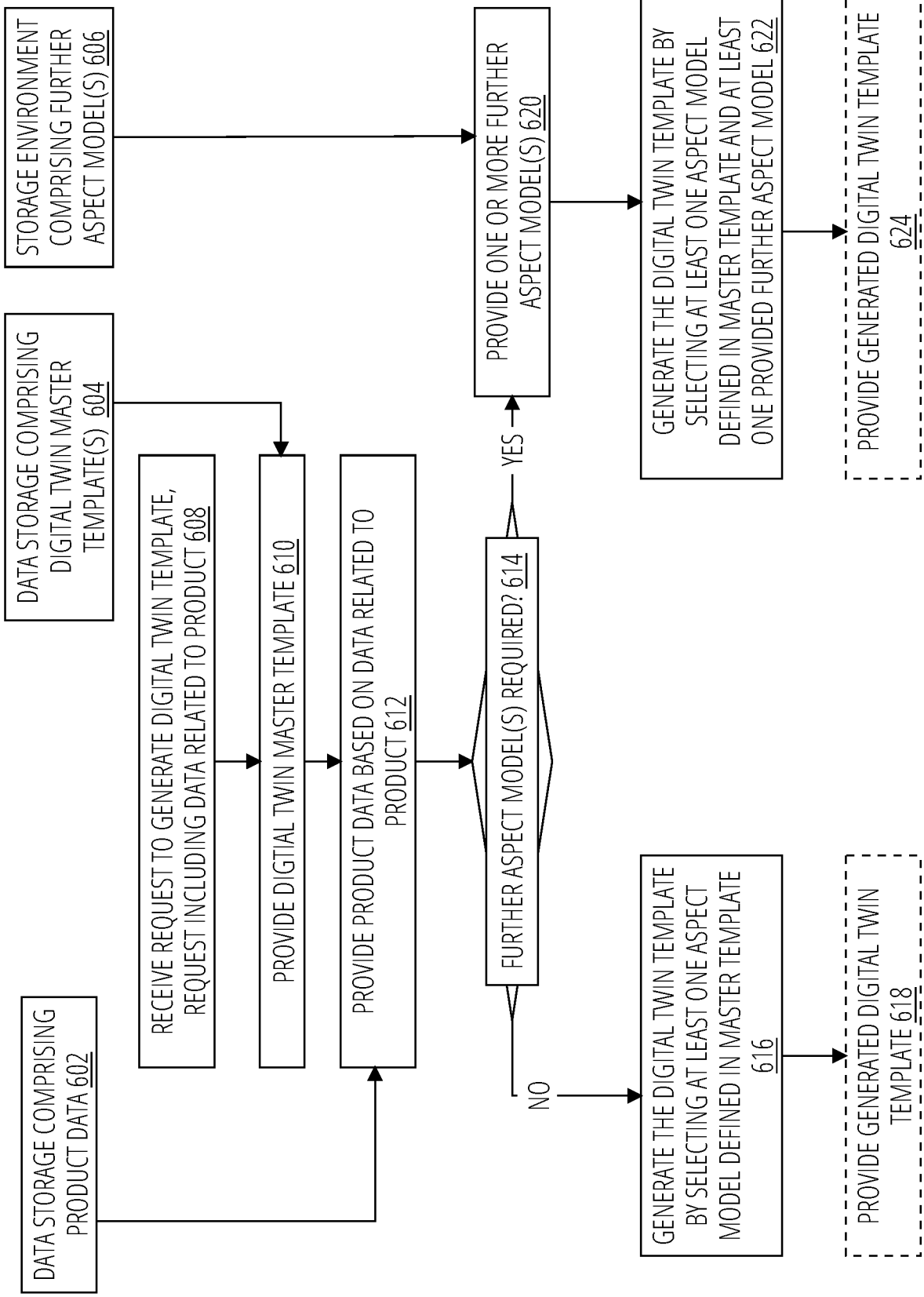
DATA STORAGE COMPRISING PRODUCT DATA 602
DATA STORAGE COMPRISING DIGITAL TWIN MASTER TEMPLATE(S) 604
STORAGE ENVIRONMENT COMPRISING FURTHER ASPECT MODEL(S) 606
RECEIVE REQUEST TO GENERATE DIGITAL TWIN TEMPLATE, REQUEST INCLUDING DATA RELATED TO PRODUCT 608
PROVIDE DIGITAL TWIN MASTER TEMPLATE 610
PROVIDE PRODUCT DATA BASED ON DATA RELATED TO PRODUCT 612
FURTHER ASPECT MODEL(S) REQUIRED? 614
YES
NO
PROVIDE ONE OR MORE FURTHER ASPECT MODEL(S) 620
GENERATE THE DIGITAL TWIN TEMPLATE BY SELECTING AT LEAST ONE ASPECT MODEL DEFINED IN MASTER TEMPLATE AND AT LEAST ONE PROVIDED FURTHER ASPECT MODEL 622
PROVIDE GENERATED DIGITAL TWIN TEMPLATE 624
GENERATE THE DIGITAL TWIN TEMPLATE BY SELECTING AT LEAST ONE ASPECT MODEL DEFINED IN MASTER TEMPLATE 616
PROVIDE GENERATED DIGITAL TWIN TEMPLATE 618

FIG. 6A

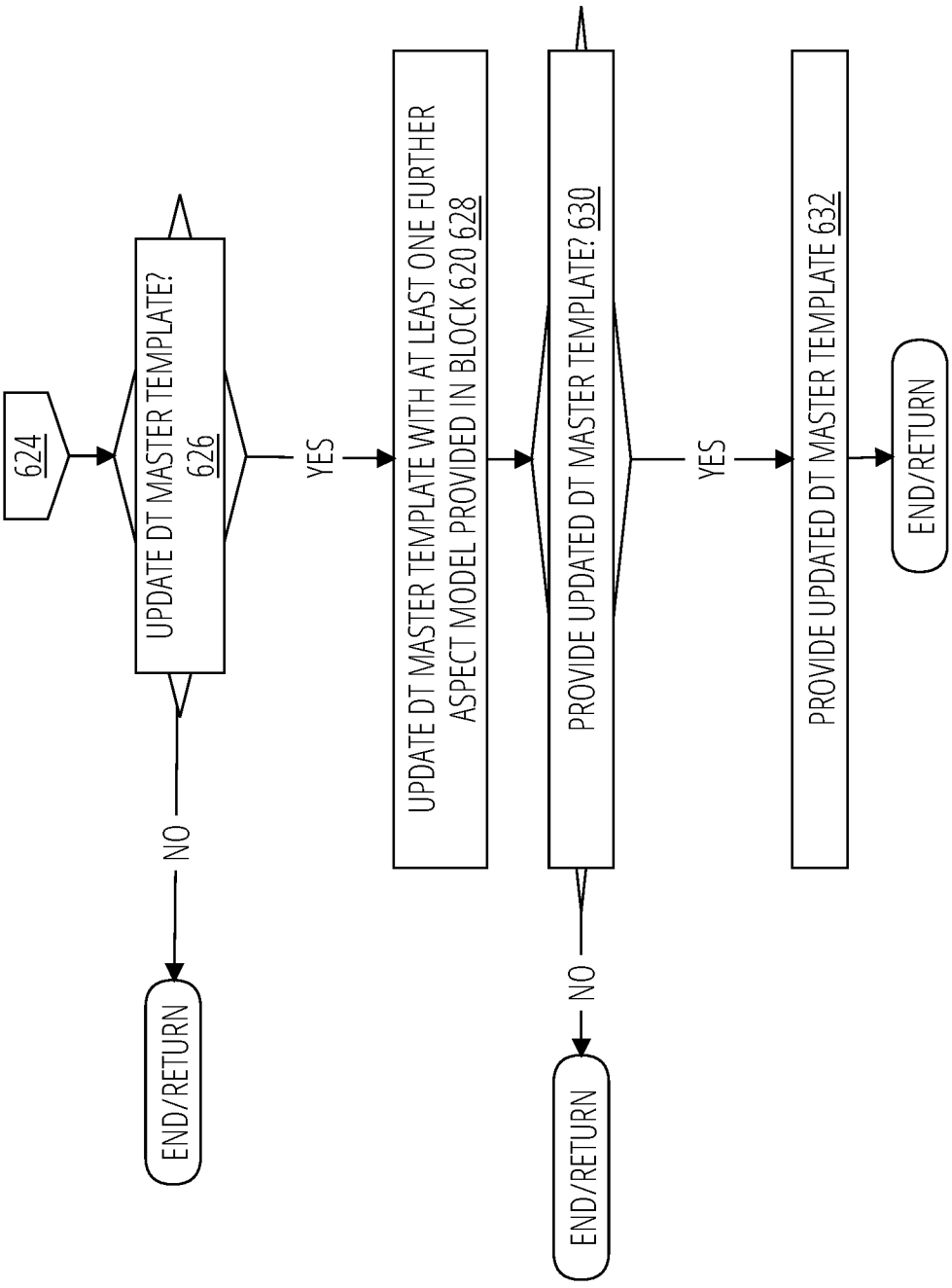
624
UPDATE DT MASTER TEMPLATE? 626
YES
NO
END/RETURN
UPDATE DT MASTER TEMPLATE WITH AT LEAST ONE FURTHER ASPECT MODEL PROVIDED IN BLOCK 620 628
PROVIDE UPDATED DT MASTER TEMPLATE? 630
YES
NO
END/RETURN
PROVIDE UPDATED DT MASTER TEMPLATE 632
END/RETURN

FIG. 6B

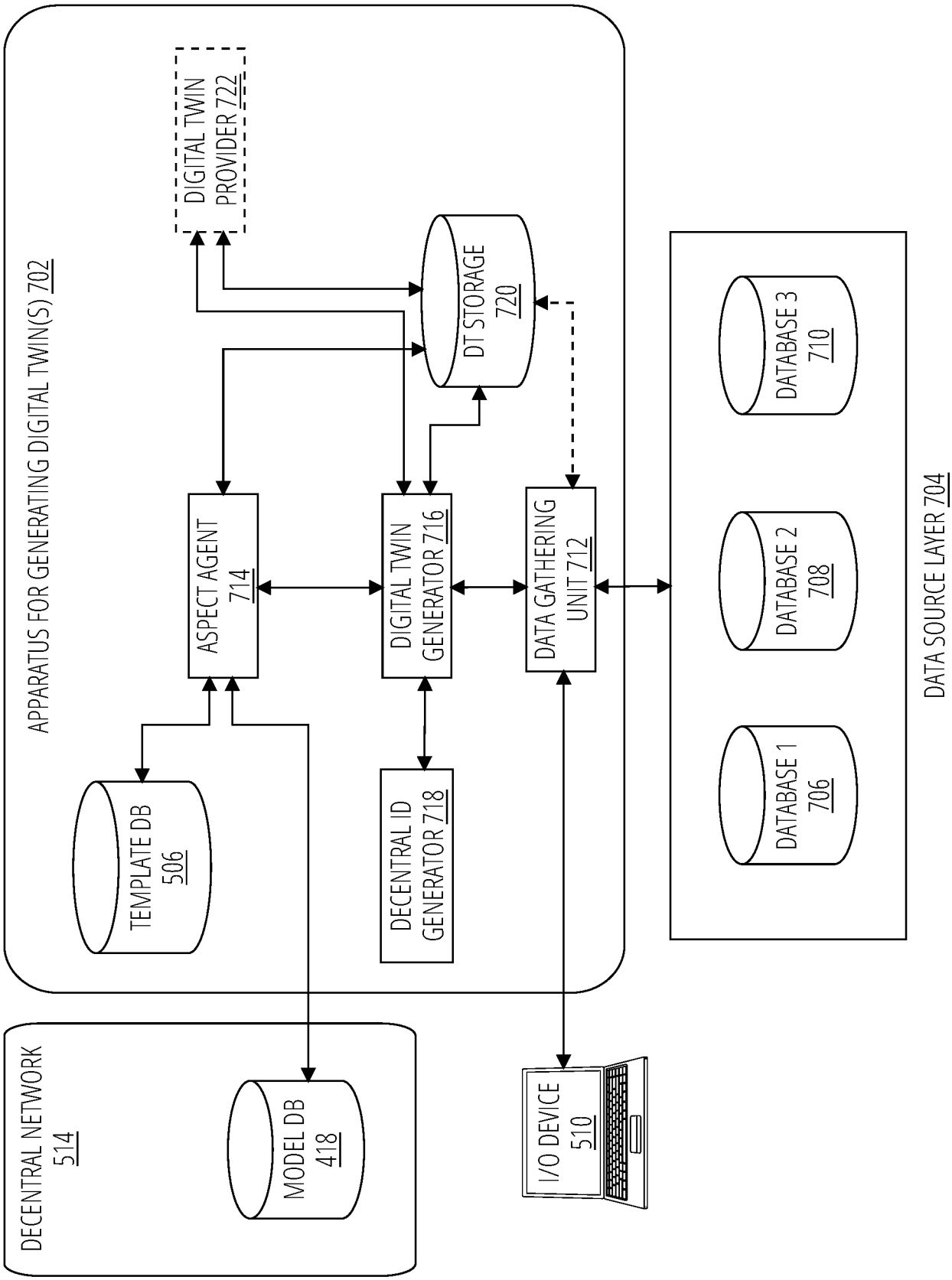
APPARATUS FOR GENERATING DIGITAL TWIN(S) 702
DIGITAL TWIN PROVIDER 722
DT STORAGE 720
ASPECT AGENT 714
DIGITAL TWIN GENERATOR 716
DATA GATHERING UNIT 712
TEMPLATE DB 506
DECENTRAL ID GENERATOR 718
DECENTRAL NETWORK 514
MODEL DB 418
I/O DEVICE 510
DATABASE 3 710
DATABASE 2 708
DATABASE 1 706
DATA SOURCE LAYER 704

FIG. 7A

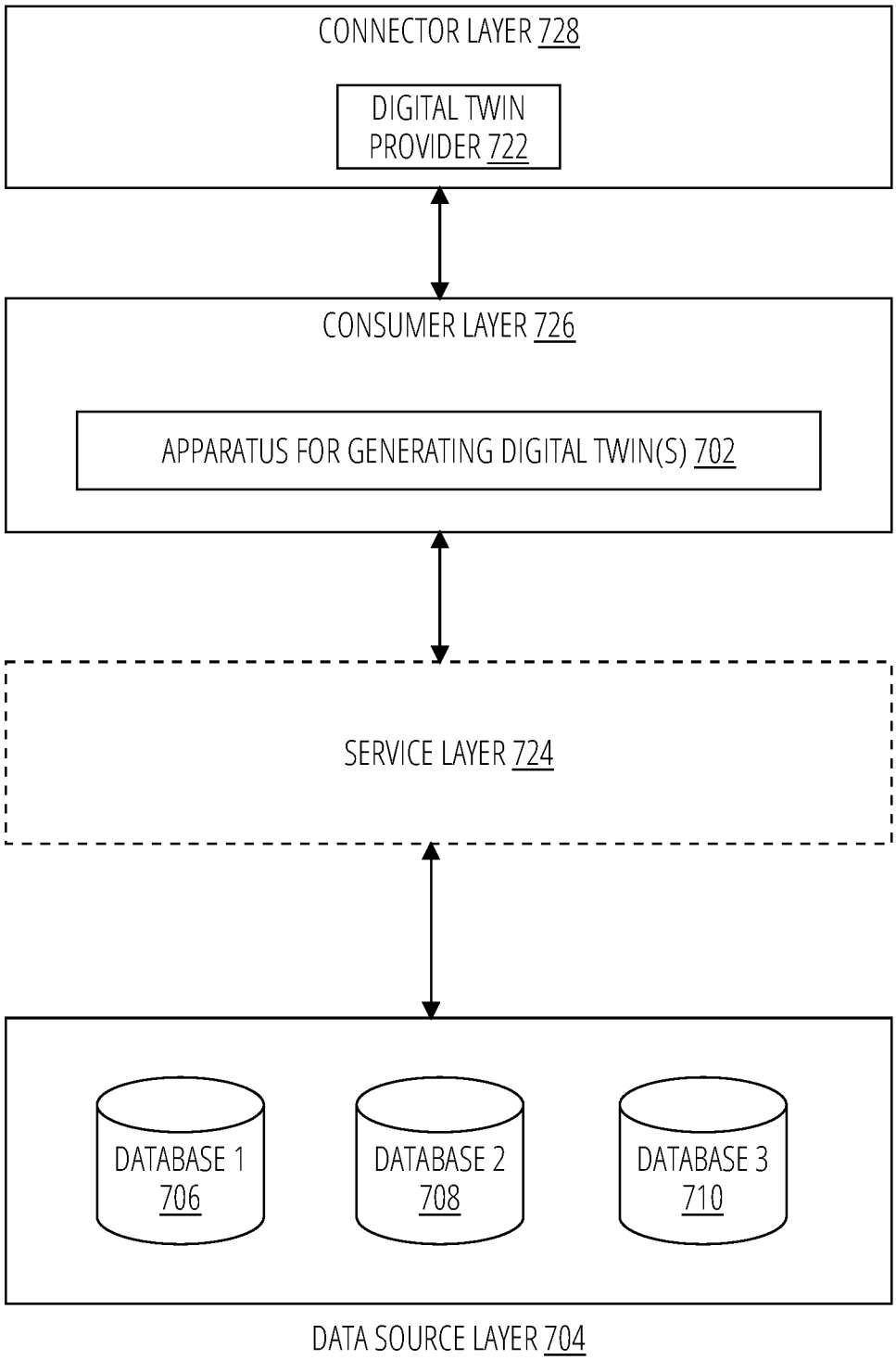
CONNECTOR LAYER 728
DIGITAL TWIN PROVIDER 722
CONSUMER LAYER 726
APPARATUS FOR GENERATING DIGITAL TWIN(S) 702
SERVICE LAYER 724
DATABASE 1 706
DATABASE 2 708
DATABASE 3 710
DATA SOURCE LAYER 704

FIG. 7B

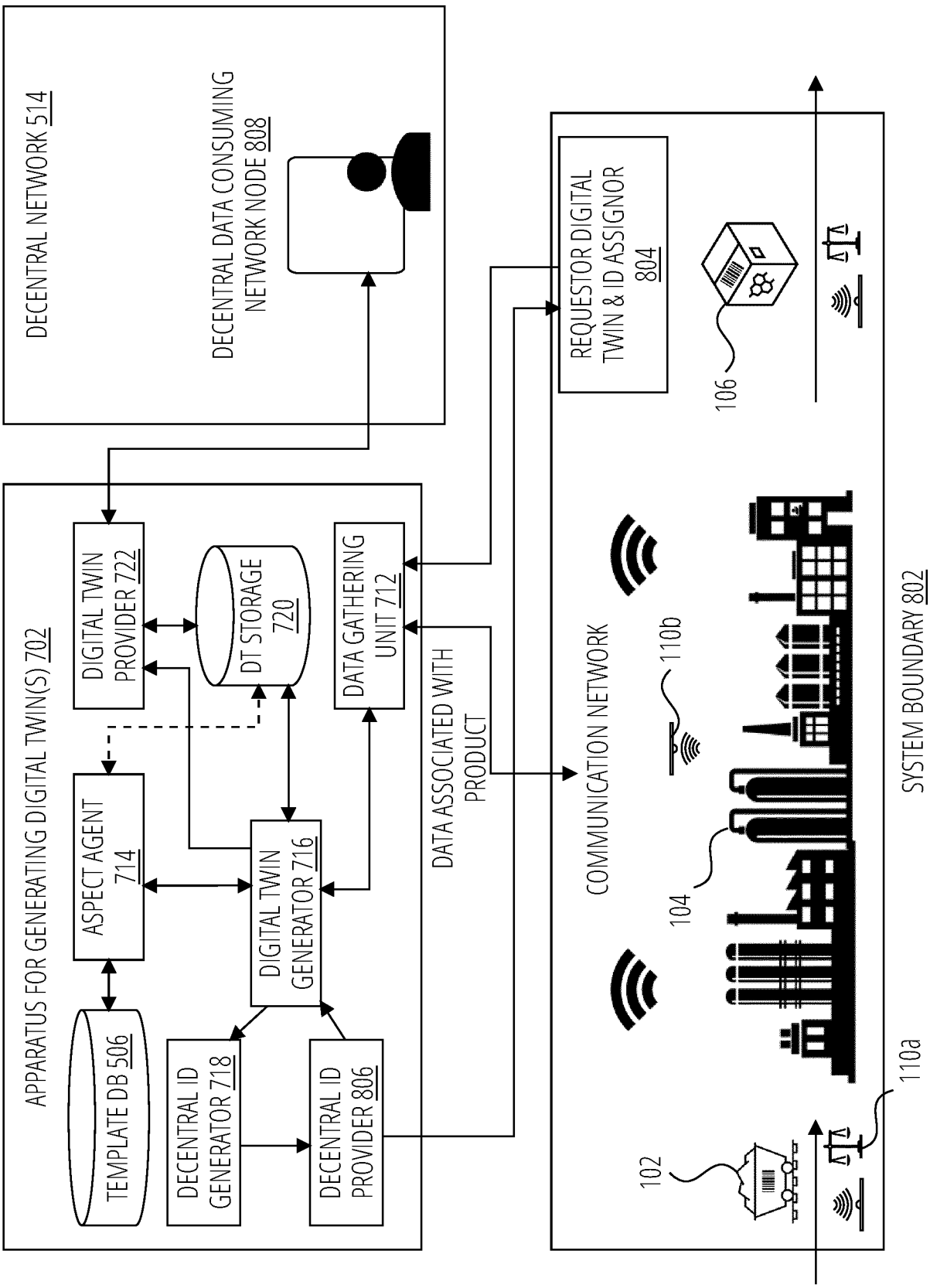
DECENTRAL NETWORK 514
DECENTRAL DATA CONSUMING NETWORK NODE 808
APPARATUS FOR GENERATING DIGITAL TWIN(S) 702
DIGITAL TWIN PROVIDER 722
DT STORAGE 720
DATA GATHERING UNIT 712
ASPECT AGENT 714
DIGITAL TWIN GENERATOR 716
TEMPLATE DB 506
DECENTRAL ID GENERATOR 718
DECENTRAL ID PROVIDER 806
DATA ASSOCIATED WITH PRODUCT
REQUESTOR DIGITAL TWIN & ID ASSIGNOR 804
COMMUNICATION NETWORK
106
110b
104
102
110a
SYSTEM BOUNDARY 802

FIG. 8

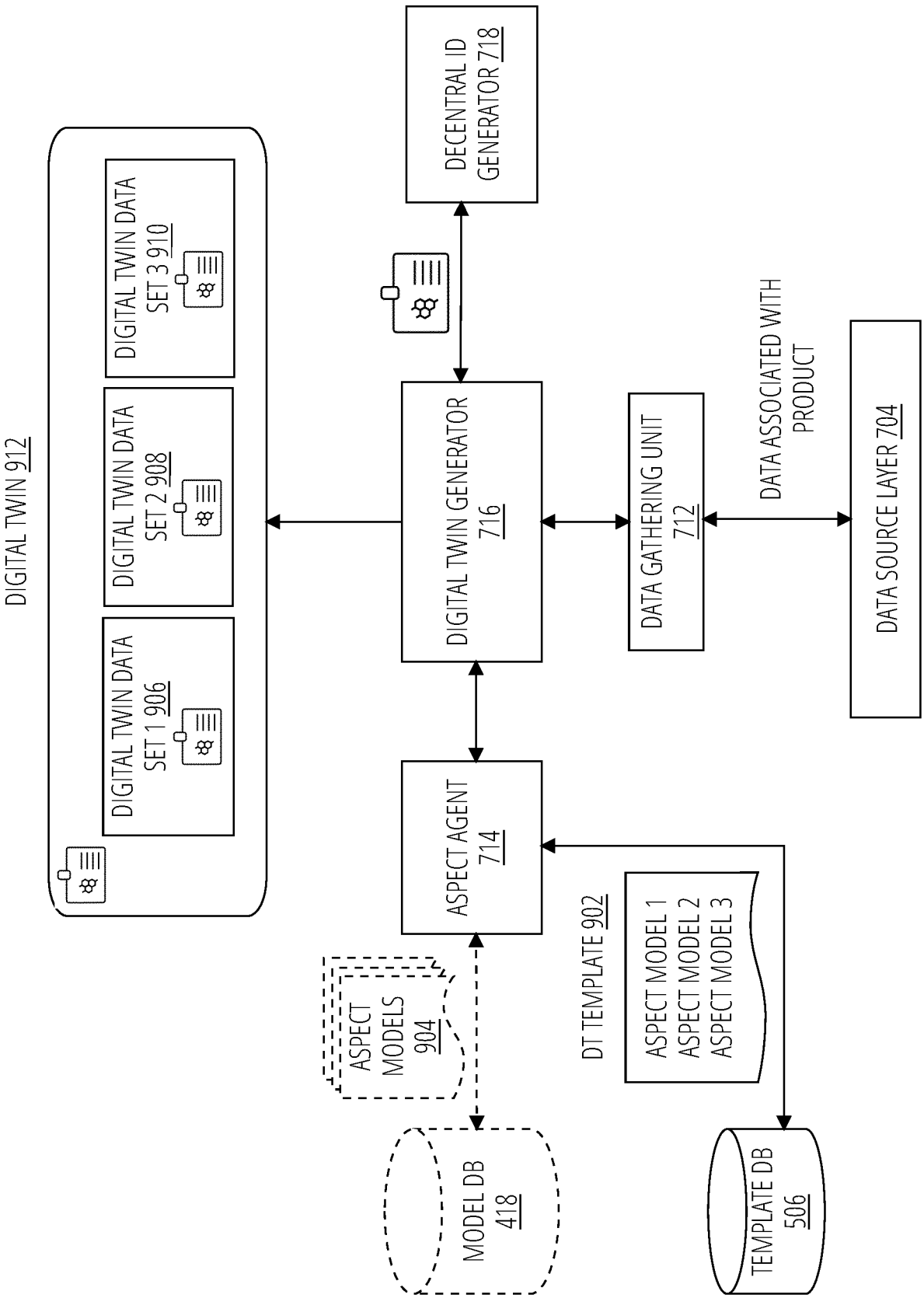
DIGITAL TWIN 912
DIGITAL TWIN DATA SET 1 906
DIGITAL TWIN DATA SET 2 908
DIGITAL TWIN DATA SET 3 910
DECENTRAL ID GENERATOR 718
DIGITAL TWIN GENERATOR 716
DATA GATHERING UNIT 712
DATA ASSOCIATED WITH PRODUCT
DATA SOURCE LAYER 704
ASPECT AGENT 714
ASPECT MODELS 904
MODEL DB 418
DT TEMPLATE 902
ASPECT MODEL 1
ASPECT MODEL 2
ASPECT MODEL 3
TEMPLATE DB 506

FIG. 9

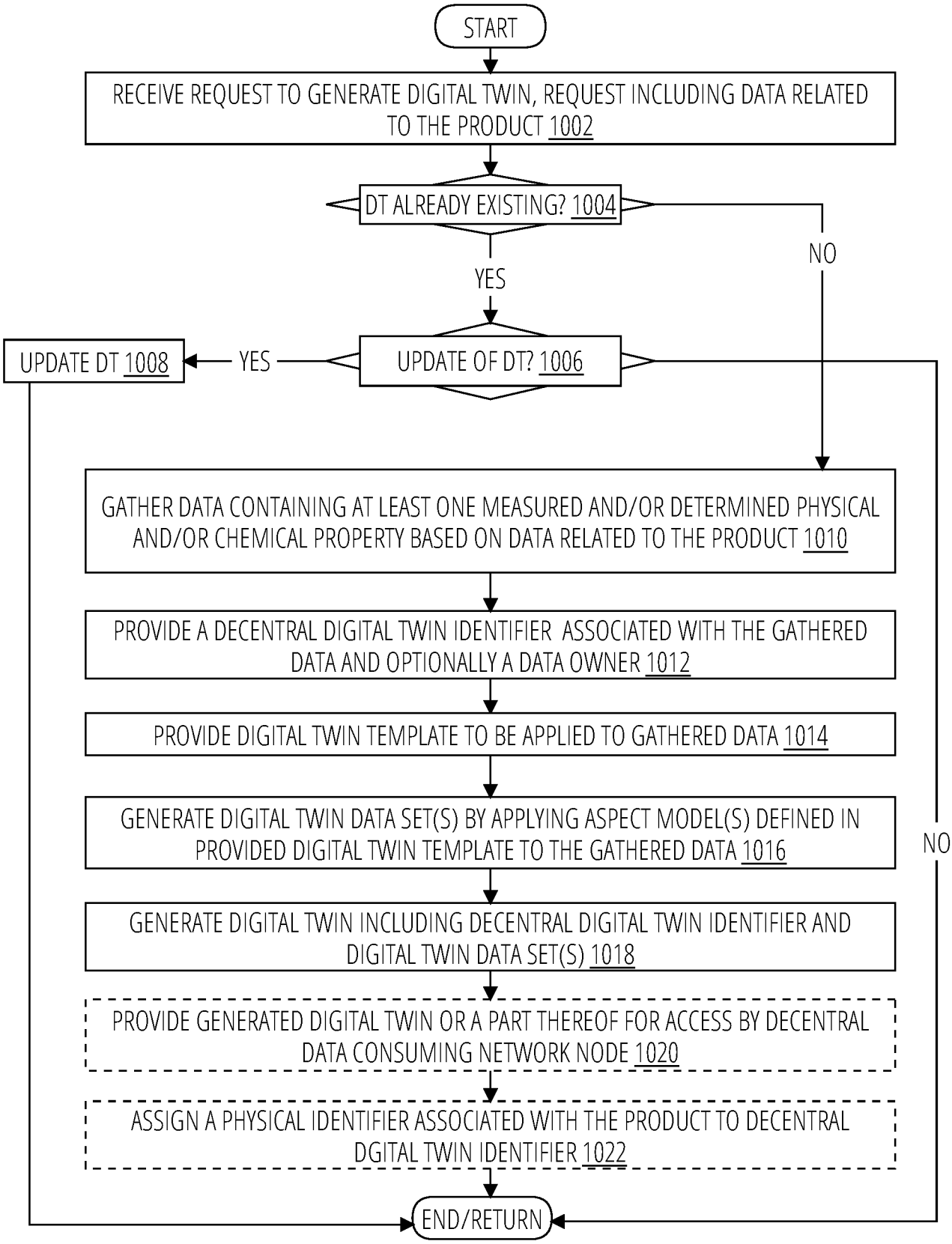
START
RECEIVE REQUEST TO GENERATE DIGITAL TWIN, REQUEST INCLUDING DATA RELATED TO THE PRODUCT 1002
DT ALREADY EXISTING? 1004
NO
YES
UPDATE OF DT? 1006
YES
UPDATE DT 1008
GATHER DATA CONTAINING AT LEAST ONE MEASURED AND/OR DETERMINED PHYSICAL AND/OR CHEMICAL PROPERTY BASED ON DATA RELATED TO THE PRODUCT 1010
PROVIDE A DECENTRAL DIGITAL TWIN IDENTIFIER ASSOCIATED WITH THE GATHERED DATA AND OPTIONALLY A DATA OWNER 1012
PROVIDE DIGITAL TWIN TEMPLATE TO BE APPLIED TO GATHERED DATA 1014
GENERATE DIGITAL TWIN DATA SET(S) BY APPLYING ASPECT MODEL(S) DEFINED IN PROVIDED DIGITAL TWIN TEMPLATE TO THE GATHERED DATA 1016
NO
GENERATE DIGITAL TWIN INCLUDING DECENTRAL DIGITAL TWIN IDENTIFIER AND DIGITAL TWIN DATA SET(S) 1018
PROVIDE GENERATED DIGITAL TWIN OR A PART THEREOF FOR ACCESS BY DECENTRAL DATA CONSUMING NETWORK NODE 1020
ASSIGN A PHYSICAL IDENTIFIER ASSOCIATED WITH THE PRODUCT TO DECENTRAL DGITAL TWIN IDENTIFIER 1022
END/RETURN

FIG. 10

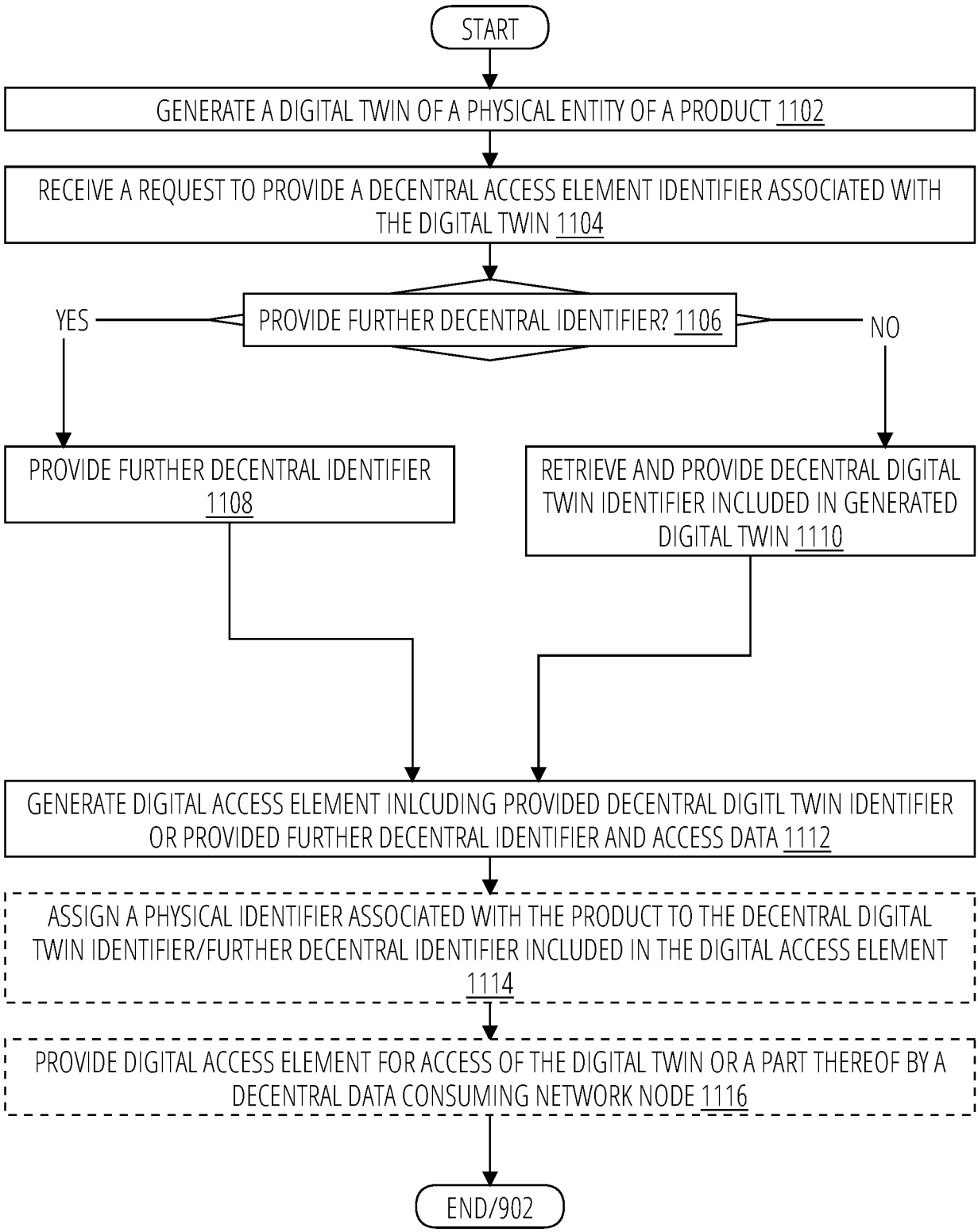
START
GENERATE A DIGITAL TWIN OF A PHYSICAL ENTITY OF A PRODUCT 1102
RECEIVE A REQUEST TO PROVIDE A DECENTRAL ACCESS ELEMENT IDENTIFIER ASSOCIATED WITH THE DIGITAL TWIN 1104
PROVIDE FURTHER DECENTRAL IDENTIFIER? 1106
YES
NO
PROVIDE FURTHER DECENTRAL IDENTIFIER 1108
RETRIEVE AND PROVIDE DECENTRAL DIGITAL TWIN IDENTIFIER INCLUDED IN GENERATED DIGITAL TWIN 1110
GENERATE DIGITAL ACCESS ELEMENT INLCUDING PROVIDED DECENTRAL DIGITL TWIN IDENTIFIER OR PROVIDED FURTHER DECENTRAL IDENTIFIER AND ACCESS DATA 1112
ASSIGN A PHYSICAL IDENTIFIER ASSOCIATED WITH THE PRODUCT TO THE DECENTRAL DIGITAL TWIN IDENTIFIER/FURTHER DECENTRAL IDENTIFIER INCLUDED IN THE DIGITAL ACCESS ELEMENT 1114
PROVIDE DIGITAL ACCESS ELEMENT FOR ACCESS OF THE DIGITAL TWIN OR A PART THEREOF BY A DECENTRAL DATA CONSUMING NETWORK NODE 1116
END/902

FIG. 11

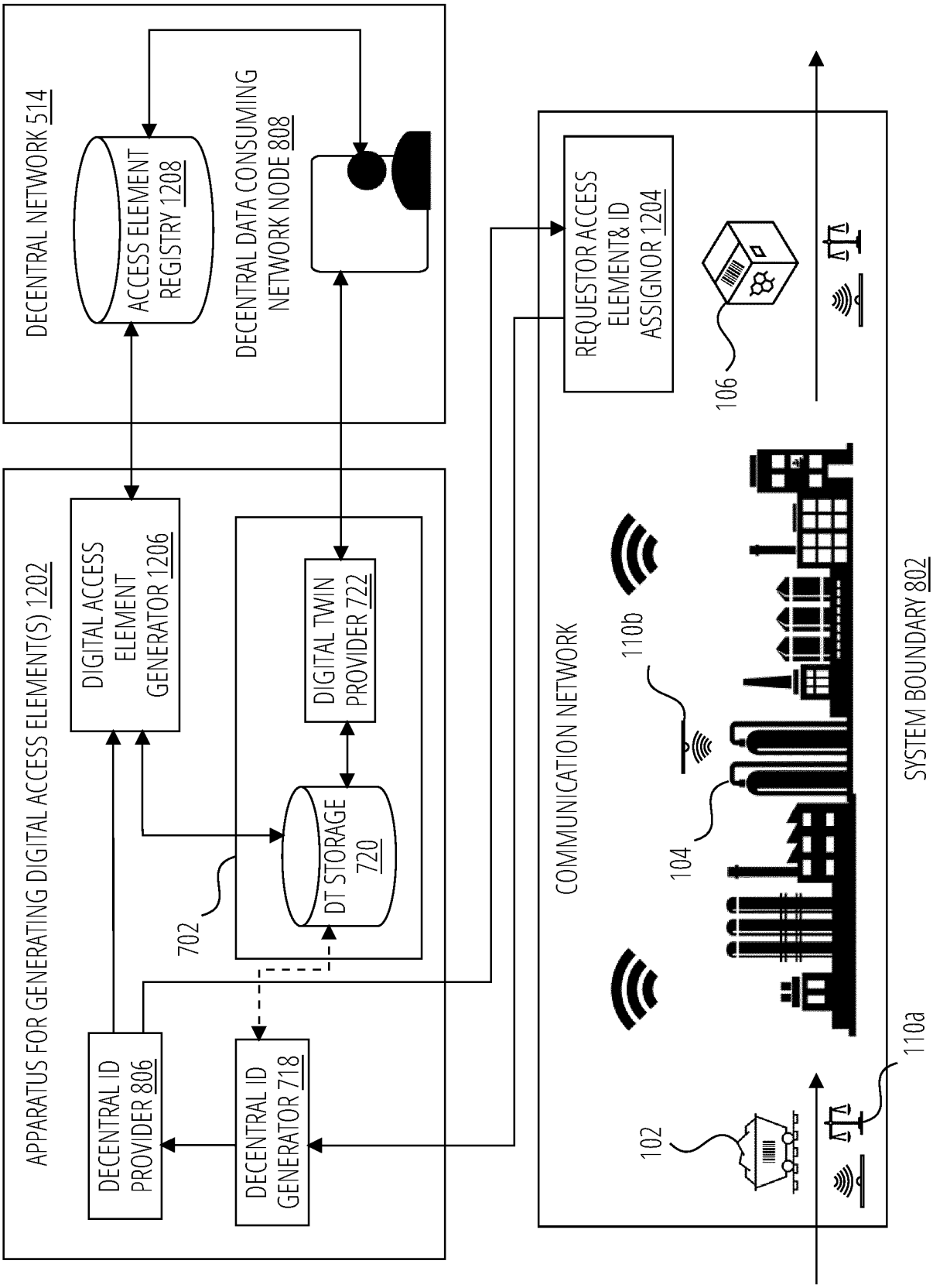
DECENTRAL NETWORK 514
ACCESS ELEMENT REGISTRY 1208
DECENTRAL DATA CONSUMING NETWORK NODE 808
APPARATUS FOR GENERATING DIGITAL ACCESS ELEMENT(S) 1202
DIGITAL ACCESS ELEMENT GENERATOR 1206
DIGITAL TWIN PROVIDER 722
DT STORAGE 720
702
DECENTRAL ID PROVIDER 806
DECENTRAL ID GENERATOR 718
REQUESTOR ACCESS ELEMENT& ID ASSIGNOR 1204
106
COMMUNICATION NETWORK
110b
104
102
110a
SYSTEM BOUNDARY 802

FIG. 12

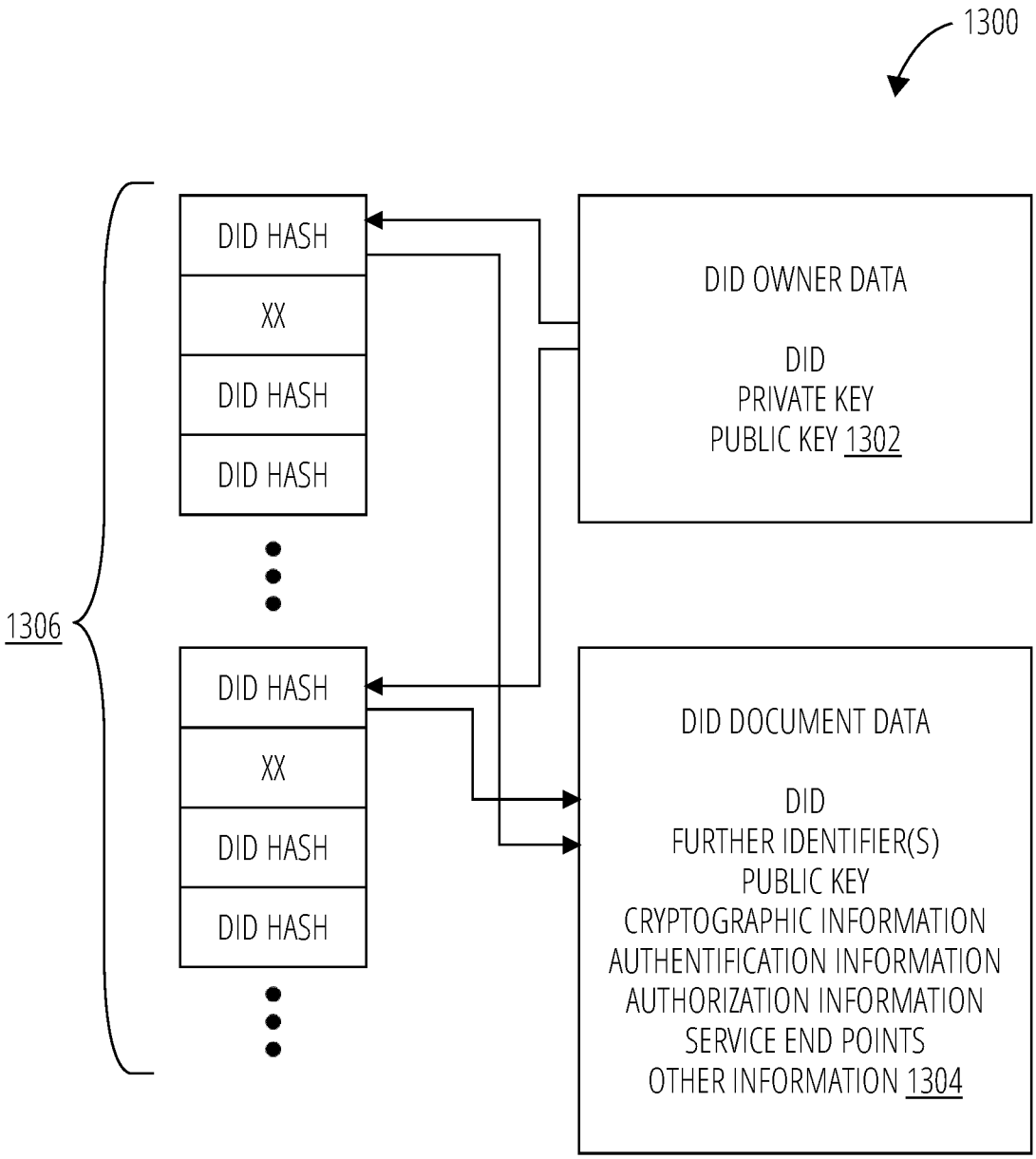
1300
DID HASH
XX
DID HASH
DID HASH
1306
DID HASH
XX
DID HASH
DID HASH
DID OWNER DATA
DID
PRIVATE KEY
PUBLIC KEY 1302
DID DOCUMENT DATA
DID
FURTHER IDENTIFIER(S)
PUBLIC KEY
CRYPTOGRAPHIC INFORMATION
AUTHENTIFICATION INFORMATION
AUTHORIZATION INFORMATION
SERVICE END POINTS
OTHER INFORMATION 1304

FIG. 13

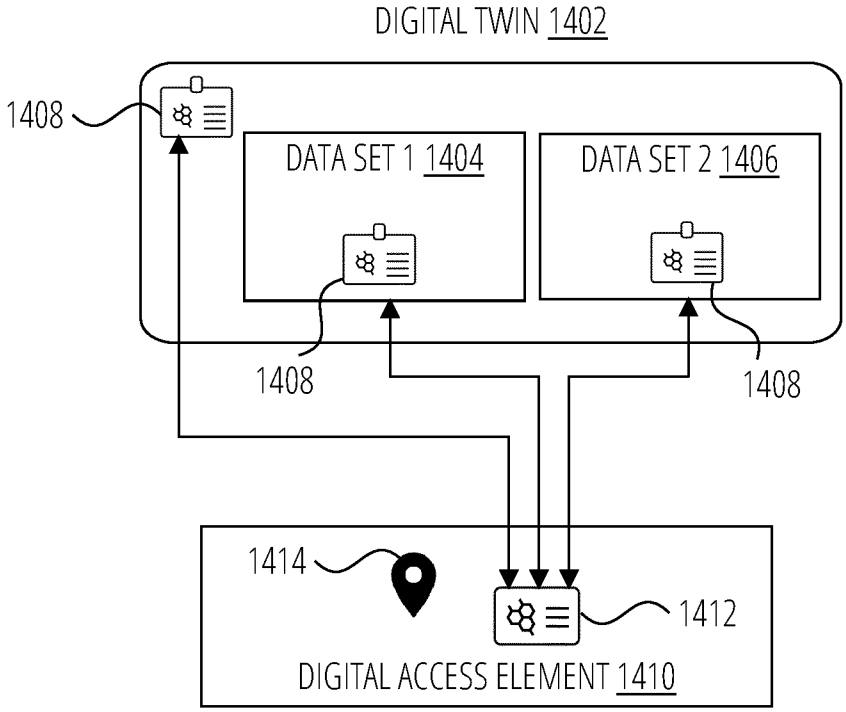

FIG. 14A

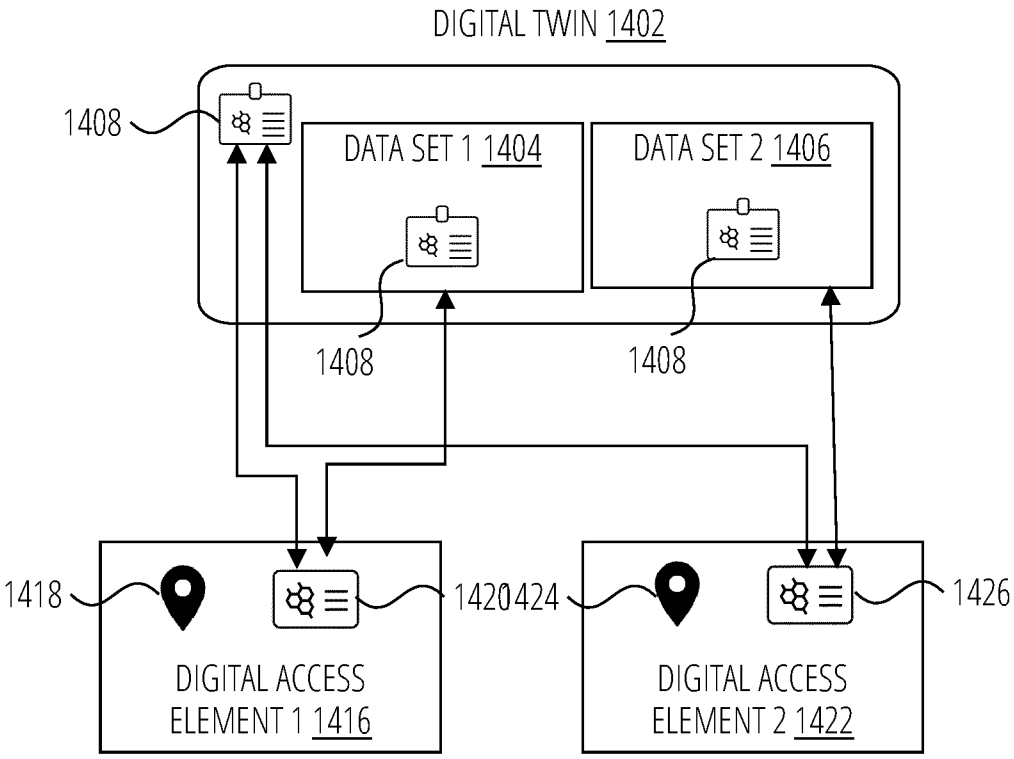

FIG. 14B

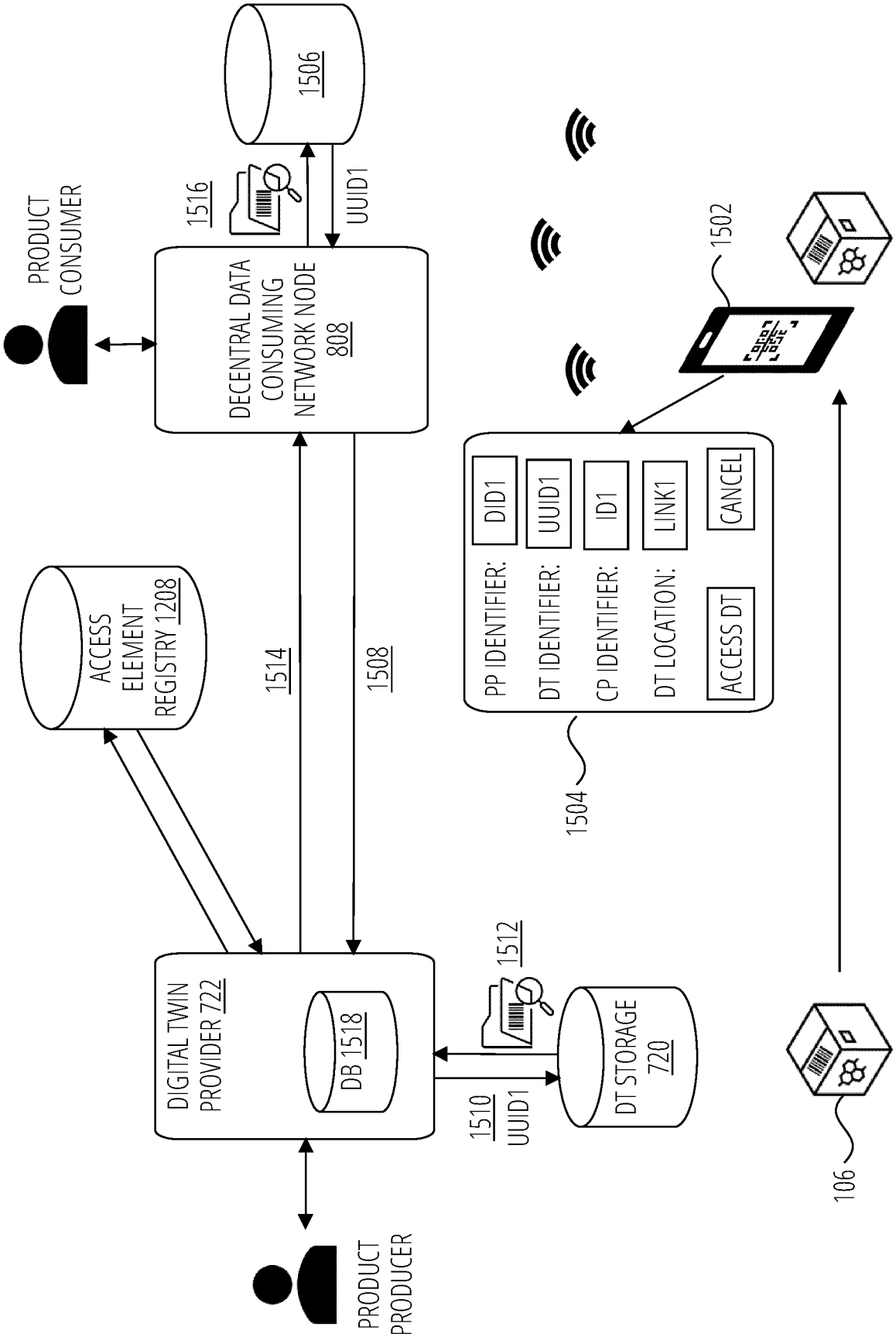
PRODUCT CONSUMER
DECENTRAL DATA CONSUMING NETWORK NODE 808
1516
UUID1
1506
1502
ACCESS ELEMENT REGISTRY 1208
1514
1508
PP IDENTIFIER:
DT IDENTIFIER:
CP IDENTIFIER:
DT LOCATION:
DID1
UUID1
ID1
LINK1
ACCESS DT
CANCEL
1504
DIGITAL TWIN PROVIDER 722
DB 1518
1512
1510
UUID1
DT STORAGE 720
106
PRODUCT PRODUCER

FIG. 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/064321

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06Q10/00 G06Q10/063 G06Q50/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2019/138662 A1 (DEUTSCH KEITH [US] ET AL) 9 May 2019 (2019-05-09)	11,12
Y	paragraph [0006] - paragraph [0007]	13-15
A	paragraph [0011] paragraph [0037] paragraph [0045] paragraph [0077] - paragraph [0079] paragraph [0087] - paragraph [0096] paragraph [0105] paragraph [0113] figures 1,5,6,7,16	1-10

Y	WO 2023/017162 A1 (BASF SE [DE]) 16 February 2023 (2023-02-16)	13-15
A	page 30, line 20 - line 35	1-12

	-/--	

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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Date of the actual completion of the international search	Date of mailing of the international search report
9 August 2024	03/09/2024

Name and mailing address of the ISA/	Authorized officer
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International application No
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Information on patent family members

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