Selected patterns for each identified key notion.

Key notions	**Ontology design pattern**
Product and components	• **Name Stub and Identifiers**: The "*Name Stub*" and '*Identifier*' patterns are used to name and uniquely identify products and components. • **AgentRole including Role-Dependent Names**: The '*AgentRole'* is used for defining various roles that entities play in the supply chain as well as to model who is responsible for various aspects such as design, manufacturing, etc. • **Quantities and Units**: This pattern is selected to represent product dimensions, weight, density, and other similar technical specifications. • **Explicit Typing**: This pattern provides a way of explicitly specifying the types of entities, in this case, different types of products. • **Provenance**: This pattern can provide a more comprehensive understanding of the history and derivation of each product, including answering the following competency questions: o Who are the suppliers or manufacturers of this product? o What processes were used to create or modify this product? o What certifications or standards does this product meet? • **Property Reification:** This pattern is used to model instructions such as assembly, disassembly, and installation instructions. • **Product:** This pattern enables the modeling of product components and compositions.
Material	• **Name Stub and Identifier**: These patterns are used to uniquely identify materials. • **Explicit Typing**: This pattern is selected because the material notion contains several attributes that describe different aspects of materials, such as their origin, composition, and properties. Adding explicit types enables to answer the following competency questions: o What is the type of this material (e.g., metal, plastic, composite)? o What types of materials are used in this product?

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	• **Provenance**: This pattern can provide a more comprehensive understanding of the history and derivation of each material, including answering the following competency questions:
	  o Who are the suppliers or manufacturers of this material?
	  o What processes were used to create or modify this material?
	  o What certifications or standards does this material meet?
	• **Spatiotemporal Extent**: This pattern is selected to track the movement of materials and all the activities related to the material that involve spatial and temporal information over time.
	  o What is the trajectory of a specific material from its origin to tis final destination?
	• **Quantities and Units**: Attributes that are quantitative in nature are contained in the notion of material. Given that the nature of quantities can be complex due to various dimensions, unit types, and measurement methods, incorporating this pattern to represent these quantities adds both rigor and flexibility to the ontology. Competency questions to answer include:
	  o What is the weight of this material in kilograms?
	  o What is the volume of this material in cubic meters?
	  o What is the environmental impact of this material in terms of its carbon footprint?
	• **Property Reification**: This pattern is selected to model complex information such as material composition with additional contextual information.
	  o What is the detailed composition of a specific material, including the proportions of its components?
	• **Material:** This pattern enables the representation of what a material is made of at the chemical level by defining it as a collection of molecular entities. It provides the means to specify the granular makeup of materials including individual atoms, ions, or molecules. Moreover, it models chemical compositions and material properties, offering insights into material

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	properties from strength and toxicity to reactivity, thereby informing product design, quality control, and environmental sustainability efforts. o Which molecular entities compose a given material? o How does the chemical composition of a material affect its physical properties? • **MaterialsProperty**: With this pattern, we can connect materials to their distinct properties, taking into account the conditions under which these properties are validated, as well as who provides this information. o At what temperature can material Y withstand a certain level of tensile strength? o Who established at what temperature material C starts to melt? • **MaterialTransformation**: This pattern is selected to capture information related to transformation from raw components and the required equipment to a final manufactured Product. o Which raw materials are essential to manufacture a product? o In which location did the transformation of materials occur? o How long did the process of transforming materials take?
Manufacturer/Supplier and Manufacturing details	• **Name Stub**: This pattern makes it possible to capture the name of the manufacturers. • **AgentRole**: Manufacturers can play different roles, such as producers, importers, suppliers, or distributors. The *AgentRole* pattern can be used to differentiate these roles explicitly. o What role(s) does Manufacturer A play in the supply chain? o Are there any manufacturers that act as both producers and suppliers? • **Identifier**: This pattern is employed to model the manufacturers identifier such as the "Economic Operators Registration and Identification number (EORI)" and "unique operator identifier".

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	○ What is the unique operator identifier for Manufacturer A? • **Property Reification**: Properties like "process details" and "production information" might require additional attributes, such as the type of machinery used, the initiation date of the process, quality of control measures, etc. This pattern makes it possible to add more layers of such additional information related to manufacturing details. ○ What machinery and quality control measures are involved in the manufacturing process of 'Product X' by Manufacturer A?
Environmental impact	• **Event**: This pattern captures occurrences or activities that have a well-defined start and end. Events are linked with locations, time, and involved agents like manufacturers. Events also describe participant roles, which can range from human actors to resources. For example, this pattern can be used to model the complete lifecycle of a product, from raw material extraction to disposal, tracking its environmental impact at each stage. ○ What is the total energy consumption in the manufacturing phase of a product? ○ Who are the suppliers involved in the raw material extraction for a product? ○ What waste materials are generated during the production of the product? • **Spatiotemporal Extent**: This pattern adds granularity to the Event pattern by making it possible to model the spatial and temporal trajectory of an event over time and space. This pattern is particularly useful for detailing carbon emissions, water usage, or energy consumption at different stages and locations of an event. ○ What is the energy consumption in different stages of a product production? ○ What is the carbon emission rate at different geographical points and times during the

Key notions	Ontology design pattern
	manufacturing phase of a product? • **Quantities and Units**: This pattern quantifies various attributes of environmental impacts, such as water footprint, carbon footprint, and energy consumption, and associates them with specific events or spatiotemporal extents. By standardizing how these quantities are expressed, the pattern enables a more structured and comparative analysis of environmental data. o What is the total carbon footprint of a product from raw material extraction to consumer use? o What is the water usage during the production of a product?
Intended use and maintenance	• AgentRole: This pattern focuses on the role of agents (people, organizations, etc.) and the temporal extents during which they perform these roles. It is useful for defining roles related to maintenance tasks, such as maintenance technician, and makes it possible to specify the time duration during which a technician performs a maintenance task. o Who are the authorized maintenance technicians for a specific product and when is the maintenance scheduled? o What roles does a user play in the lifecycle of a product? • Quantities and Units: The ontology includes data properties, such as "*annualMaintenanceCost*", "*taskDuration*" and "*quantity*", which are numerical and can be considered types of quantities. The Quantity pattern provides a more structured way of representing these properties, allowing for unit conversion, better interoperability, and more precise queries. o What is the total annual maintenance cost for a specific product? o What is the remaining lifespan of a product in different units (e.g., years, months, days)? • Provenance: This pattern is designed to track the history or origin of entities and activities in an ontology. It provides a way

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	of associating agents with activities and entities, and entities with the activities that generated them. o Who performed the last maintenance task on a specific product, and when was it performed? o What is the history of ownership changes for a specific product?
End-of-life (EoL) management	• **Process**: This pattern focuses on how processes (or activities) can be represented. It distinguishes between two things: a '*Process'*, which is a general description of an activity (for example, repairing or recycling), and '*ProcessExecution'*, which is a specific instance of the process happening (for example, repairing a certain product on a specific date). '*Transformation'* is a key aspect of the *Process module*. It refers to concepts that involve taking materials or products in one state and transforming them into a different state, for example, transformation could involve taking demolished building products and materials and processing them to be reused in new construction products. This pattern lists processes involved in the EoL management of products and materials, which makes it suitable for our EoL management key notion. o What is the repairing process of a specific product? o What is the reuse process for this product? • **Event**: Our ontology revolves around the concept of EoL management for products. Each of these management strategies (recycle, reduce, remanufacture, etc.) can be thought of as an '*Event'* in the life cycle of a product. For example, when a product is recycled, a recycling event occurs. In the event pattern, there is a concept of '*ParticipantRole'*, which defines the role of an entity in an event. This can be mapped to how products or recyclers participate in these end-of-life events. For example, in the recycling event, the product's role is that of an item being recycled and the recycler's role is to carry

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	out the recycling process. Given this context, the CQs are: o When and where did a specific product undergo recycling? o Which entity (individual, organization, or machine) was responsible for recycling a particular product? o What processes or actions were part of refurbishing a given product? • **Explicit Typing**: The end-of-life product management involves various entities, such as products, participants, processes, or events. Having explicit types allows for clear differentiation between these entities. For example, while fluorescent and LED lamps are both building lighting products, they might have different recycling processes. o What is the type of end-of-life management strategies planned for a product of type 'LED bulbs'? • **Identifier**: The lifecycle of a product, from its creation to its disposal or recycling, involves numerous steps and transitions. Having unique identifiers ensures that each product or entity is individually trackable throughout its lifecycle. With unique identifiers, any discrepancies and issues at any stage can be tracked back to the specific product or process. • **Quantities and Units**: This pattern makes it possible to quantify, for example, the amount of waste created. • **Circular Value Network**: This module allows to model the roles and responsibilities of actors at the end stage of a product's lifecycle. It facilitates the identification and planning of strategies such as recycling, reusing or proper disposal by defining the processes and actors involved.
Standards	• **Provenance**: The Standard notion is built around products, standards, compliance checks, and various documentation associated with products. Knowing the provenance of this information can help determine its reliability and make it possible to track activities. For example,

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	understanding who performed a compliance check, which entity issued a standard, or the origin of a technical documentation can provide insights into the history of the product. o Who performed the compliance check for a specific product, and what standards were used during the verification? o For a given standard, what is its origin, and which organization is responsible for its creation and maintenance? • **Standard Enforcer Pattern**: This pattern provides the capability to link processes, operations, activities and services to their governing standards. It supports a flexible and compositional framework, allowing for the integration of various guidelines from multiple standards. o Which are the standards enforced by the manufacturing process of a specific product? o What are the specific rules or procedures outlined in a standard?
Certifications	• **AgentRole**: This pattern provides a structured way to represent entities (agents) and the roles they play in specific contexts. The concept of certifications involves multiple roles including certifying authority (*Agent*), product (*Agent*) and certification (*AgentRole*). Given this context, the competency questions are: o Which certifying authority issued the "Energy Efficiency Rating" for a specific product? o For a given product (*Agent*), what certifications (*AgentRole*) does it hold, and what are their respective issue and expiry dates? • **Provenance**: The '*Provenance*' pattern is used for tracking the history and certifications of a product. Certifications involve a process of validation or verification, information related to who issued the certifications, when it is issued, and possibly what evidence or process was used to grant it. o Who (which Agent) attributed the "Safety Certification" to a

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	specific product, and what was the *ProvenanceActivity* involved? • **Identifier**: This pattern makes it possible to uniquely identify entities in a standardized way. It is important to uniquely identify each certification to ensure clarity as well as to enable querying specific certifications. o Which product has the certification with the identifier xxx? o Given identifier zzz, what is the associated certification name and its issuing authority?
Classifications	• **Classification**: This pattern is used to represent the relationships between concepts (roles, tasks, classification systems) and entities (products, persons, events). We need to determine which entities are classified by specific concepts and which concepts have the ability to classify these entities. o For a given product, under which classification is it categorized? o Which category does this Product belong to? • **Identifier**: This pattern ensures that each classification has a unique identifier. This can be useful in scenarios where there are multiple classification standards or when integrating data from different sources. o Given a product, what is the unique identifier of its classification, and what additional attributes or information does that classification provide?
Supply chain information	• **Event**: The supply chain module includes events such as manufacturing, storage, distribution, transportation, delivery, etc. Each of these is modeled as an instance of an 'Event' with a spatiotemporal extent and participant roles. For each event in the supply chain module, we define its spatiotemporal properties. This could be the time and place of manufacturing, the duration of transportation, etc. In addition, for each event in the module, we identify and assign participant roles. For example, in a shipping event (an instance event of transportation) the participants could

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	include '*Sender'* (the entity sending the goods), '*Receiver'* (the entity receiving the goods), *Carrier* (the transport service responsible for shipping), '*Goods'* (the items being shipped). o For a given delivery event, who are the sender and receiver, and what goods were delivered? • **Spatiotemporal Extent**: As mentioned above, this pattern makes it possible to model the product's location and its movement through space and time. It enables to track objects or entities as they move and change over time and space. For example, tracking of goods, vehicles, shipments, or any entity that moves through the supply chain network. o At a particular point in time, where was a specified product located, and what transportation method was being used? o What are the start and end times of the transportation event for a specific shipment, and which carrier was responsible for this transportation? • **Identifier**: This pattern is used to model the identity of various entities within the supply chain. Each object or entity in the supply chain needs to be uniquely identified to avoid confusion, ensure traceability, and maintain accurate records. Identifiers also allow for the linking of different pieces of information related to the same entity. This can include linking a product to its manufacturing details, shipping information, and current location within the supply chain. • **Circular Value Network**: This module enables the modeling of collaboration among different actors within the supply chain such as organizations, businesses, or individuals. It facilitates a smooth flow of products, information, and values from raw material extraction to product delivery and beyond.