1. **Mapping Sensor Data Models**
   1. **Semantic alignment between the IFC and SAREF sensor models**

The first step involved aligning the IFC and SAREF sensor models following the methodology outlined in Section 3 to compare and contrast both models for semantic alignment.

*4.1.1 Determine the Domain and Scope of the SAREF Ontology*

The initial phase involved defining and identifying the structure, scope, and domain of SAREF sensor models, laying the essential groundwork for semantic interoperability and mapping. Clarifying the ontology's scope is pivotal for establishing a standardized foundation for seamless data exchange and integration. The hierarchical Representation provides a clear structure for understanding the relationships and classifications within the SAREF ontology, showcasing the interconnected elements that define smart devices and their functionalities. Figure 3 illustrates the overarching hierarchy of the SAREF ontology, delineating into several key classes, including *saref:Command,* saref:Commodity, saref:Function, saref:Measurement, saref:Profile, saref:Property, saref:Service, saref: State, saref:Task, saref:Unit of Measure, and saref:Device. The saref:Device encompasses various functions, including saref:Function, from which saref:Sensor emanates.

Figure 3: General saref: Sensor Class Hierarchy

Figure 4 also represents a visual encapsulation of the core domain within the SAREF sensor ontology, utilising the OntoGraf visualisation tool in Protégé version 5.6.3. The visualization is a graphical representation of the fundamental elements and relationships that constitute the core of the sensor ontology. The left panel describes the SAREF classes, and the right side of the figure depicts the ontoGraf visualisation.

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Figure 4: A screenshot of the SAREF Sensor ontology core domain visualization using OntoGraf in Protégé v.5.6.3

**4.1.1.1 saref:Sensor Attributes** *(what Information is added?)*

The SAREF:Sensor Attributes are identified in Table 2 and Figure 5 based on the Information added to the element. These provide a comprehensive overview of key attributes within the SAREF ontology, designed explicitly for sensor-related entities. These attributes encompass diverse aspects, ranging from the definition of a device and its associated functions (saref:Device) to the specification of tasks (saref:Task) and states (saref:State) that a device can exhibit. The Table also addresses commodities (saref:Commodity) such as energy sources and general properties (saref:Property) that can be sensed or controlled in various settings. Additionally, it delves into more specialized attributes like energy (saref: Energy) and power (saref:Power), outlining their measurement characteristics. The inclusion of functionality (saref:Function) and the Representation of measured values (saref:Measurement) further enrich the understanding of sensor attributes. Each attribute is accompanied by a detailed description, promoting clarity and alignment with the overarching SAREF ontology, thereby fostering a standardised and interoperable approach to sensor data within the IoT ecosystem. Figure 5 presents a visual representation of the saref:Sensor Attributes, emphasising the relevant characteristics enclosed within the shaded area.

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Figure 5:OntoGraf visualization of the saref:Sensor Attributes (shaded portion)

Table 2: saref:Sensor Attributes showing descriptions

|  |  |
| --- | --- |
| **Saref:Sensor Attributes** | **Description** |
| saref:Device | *“A tangible object designed to accomplish a particular task. In order to accomplish this task, the device performs one or more functions. For example, a washing machine is designed to wash (task) and to accomplish this task it performs a start and stop function.”* |
| saref:Profile | *“A specification associated to a device to collect information about a certain Property (e.g., Energy) for optimizing its usage in the home, office or building in which the device is located.”* |
| saref:Service | *“A service is a representation of a function to a network that makes the function discoverable, registerable, remotely controllable by other devices in the network. A service can represent one or more functions. A Service is offered by a device that wants (a certain set of) its function(s) to be discoverable, registerable, remotely controllable by other devices in the network.”* |
| saref:Task | “The goal for which a device is designed (from a user perspective)” |
| saref:State | “The state in which a device can be found, e.g., ON/OFF/STANDBY, or ONLINE/OFFLINE.” |
| saref:Commodity | “A marketable item for which there is demand, but which is supplied without qualitative differentiation across a market. SAREF refers to energy commodities such as electricity, gas, coal and oil.” |
| saref:Property | “Anything that can be sensed, measured or controlled in households, common public buildings or offices.” |
| saref:Energy | “A saref:Property related to some measurements that are characterised by a certain value measured in an energy unit (such as Kilowatt\_Hour or Watt\_hour).” |
| saref:Power | “A saref:Property related to some measurements that are characterised by a certain value that is measured in a power unit (such as watt or kilowatt).” |
| saref:Function | “The functionality necessary to accomplish the task for which a device is designed”. |
| saref:Measurement | “Represents the measured value made over a property. It is also linked to the unit of measure in which the value is expressed and the timestamp of the measurement”. |

**4.1.1.2 saref:Sensor Properties** *(How do I look and what are my characteristics?)*

In Table 3 The saref:Sensor Properties encompass key attributes defining the characteristics and functionalities of sensors within the SAREF ontology. These properties include saref:hasTimestamp, specifying the timestamp of an entity; saref:hasSensingRange, delineating the range of sensor detection; and saref:hasSensorType, identifying the type of sensor detection (e.g., Temperature, Occupancy). Additionally, saref:hasManufacturer establishes the manufacturer of a device, saref:measuresProperty signifies the property measurable by a device, and saref:hasValue denotes the value of a property (e.g., energy or power). The SAREF ontology introduces saref:SensingFunction, a function facilitating data transmission from sensors, and saref:hasState, identifying the state type of a device. The set of properties aims to provide a structured foundation for describing and interlinking sensor-related Information.

Table 3: saref:Sensor Properties

|  |  |
| --- | --- |
| **aref:Sensor Properties** | **Description** |
| saref:hasTimestamp | 'A relationship stating the timestamp of an entity (e.g., a measurement).' |
| saref:hasSensingRange | 'A relationship between a sensing function and a measurement identifying the range of a sensor detection.' |
| saref:hasSensorType | 'A relationship identifying the sensing type of a sensor detection (i.e., Temperature, Occupancy, Humidity, Motion, Smoke, Pressure, etc.).' |
| saref:hasManufacturer | 'A relationship identifying the manufacturer of an entity (e.g., device). The value is expected to be a string or a string with a language tag.' |
| saref:measuresProperty | 'A relationship specifying the property that can be measured by a certain device.' |
| saref:hasValue | 'A relationship defining the value of a certain property, e.g., energy or power. Note that, even if numeric values are expected to enable reasoning, measurement values could use other datatypes.' |
| saref:SensingFunction | "'A function that allows transmitting data from sensors, such as measurement values (e.g., temperature) or sensing data (e.g., occupancy).'" |
| saref:hasState | 'A relationship identifying the type of state of a device.' |

**4.1.1.3 saref:Sensor Relations** *(which objects are my parents and children?)*

saref:Sensor Relations establish the parent-child connections between different sensor objects, helping to define their hierarchy and associations. Within the framework, there are various sensor types like "saref:Temperature sensor," "saref:Smoke sensor," "saref:LightSensor," "saref:DetectingSensor," "saref:MotionSensor," and "saref:PresenceSensor."The parent class is the "saref:Device". These relationships indicate the broader categories and specialised sensor types, highlighting how they are connected within the sensor taxonomy.

**4.1.1.4 saref:Sensor Interactions** *(which objects do I interact with?)*

From Table 4, the saref:Sensor Interaction elements delineate critical relationships and functionalities within the SAREF ontology. Fundamental interactions include saref:hasFunction, identifying the function of a device, and saref:hasProfile, associating a profile with a device. The saref:offers relationship signifies the connection between a device and a service it provides. Additionally, saref:UnitOfMeasure establishes the standard for measuring a quantity or property, while saref:isMeasuredIn specifies the unit of measure for a particular entity. The relation saref:makesMeasurement links a device to the measurements it conducts, encompassing the value, unit of measure, and the related property. Other interactions involve saref:accomplishes, connecting a device to the task it achieves, saref:consistsOf, indicating composite entities; and saref:controlsProperty, specifying the property controllable by a device. Lastly, saref:isUsedFor denotes the commodity a device is utilised for. These interactions collectively provide a comprehensive framework for describing and interconnecting sensor-related functionalities in the SAREF ontology.

Table 3: saref:Sensor Interactions

|  |  |
| --- | --- |
| **Saref:Sensor Interaction** | **Description** |
| saref:hasFunction | 'A relationship identifying the function of a device.' |
| saref:hasProfile | 'A relationship associating a profile to a certain device.' |
| saref:offers | 'A relationship between a device and a service.' |
| saref:UnitOfMeasure | 'The unit of measure is a standard for measurement of a quantity, such as a property.' |
| saref:isMeasuredIn | 'A relationship identifying the unit of measure used for a certain entity.' |
| saref:makesMeasurement | 'A relation between a device and the measurements it makes. Such measurement will link together the value of the measurement, its unit of measure and the property to which it relates.' |
| saref:accomplishes | 'A relationship between a certain entity (e.g., a device) and the task it accomplishes.' |
| saref:consistsOf | 'A relationship indicating a composite entity that consists of other entities (e.g., a temperature/humidity sensor that consists of a temperature sensor and a humidity sensor).' |
| saref:controlsProperty | 'A relationship specifying the property that can be controlled by a certain device.' |
| saref:isUsedFor | 'A relationship specifying the commodity for which a device is used for.' |

**4.1.1.5 saref:Sensor Geometry** *(what are my dimensions and defaults?)*

The existing specification for saref: The sensor faces a notable limitation in not incorporating a dedicated, predefined property or attribute to articulate Information regarding a sensor's geometric aspects or dimensions. In essence, there is a recognized gap in the ontology's ability to describe the dimensions or geometry of sensors comprehensively. To address this deficiency, a forward-looking proposal is presented. It suggests introducing new properties, specifically saref:hasGeometry or saref:hasDimensions, within the saref:Sensor ontology. These proposed properties would serve as structured fields for capturing and conveying details about the geometry or dimensions of sensors. The envisaged outcome is a more robust and inclusive representation that accommodates diverse geometric characteristics associated with different types of sensors. Another alternative to capturing the saref:Sensor dimensions or geometry could be exploring options that could be embedded within existing properties like saref:hasManufacturer or saref:hasModel. This indirect association proposes that Information about the manufacturing process or the model of a sensor may inherently include details about its geometry.

**4.1.2 *IfcSensor* Data Models-Domains and Scope of the Ontology**

The IFC incorporates four essential conceptual layers. These layers consist of the Resource, Core, Interoperability, and Domain-specific layers. The Domain-specific layer further categorizes definitions based on various industry disciplines, including *IfcArchitectureDomain, IfcBuildingControlsDomain, IfcConstructionMgmtDomain, IfcElectricalDomain, IfcHvacDomain, IfcPlumbingFireProtectionDomain, IfcPortsAndWaterwaysDomain, IfcRailDomain, IfcRoadDomain, IfcStructuralAnalysisDomain,* and *IfcStructuralElementsDomain.* The *IfcBuildingControlsDomain* schema is a component within the Domain Layer of the IFC Model. It expands upon the principles related to building services introduced in the *IfcSharedBldgServiceElements* schema. This schema establishes the concepts associated with building automation, control, instrumentation, and alarm systems. The *IfcBuildingControlsDomain* schema facilitates the Representation of various aspects, such as different types and instances of actuators, alarms, controllers, sensors, flow instruments, and unitary control elements. The *IfcBuildingControlsDomain* entities/class include *IfcActuator, IfcActuatorType, IfcAlarm, IfcAlarmType, IfcController, IfcControllerType, IfcFlowInstrument, IfcFlowInstrumentType, IfcSensor, IfcSensorType, IfcUnitaryControlElement* and *IfcUnitaryControlElementType* as illustrated in the Figure 6.

Figure 6: IfcSensor Hierarchy

Also, there is a difference between the IfcSensor and IfcSensorType. The *IfcSensor* represents individual sensor instances, while the IfcSensorType defines the common properties and characteristics of a particular type of sensor. "IfcSensorType" is used to create standardised templates for similar sensors, making it more efficient to model and manage multiple instances of the same sensor type within a project.

* + - 1. **IfcSensor Attributes** *(what Information is added?)*

From Table 5, IfcSensor Attributes encompass the Information added at different levels of the IFC sensor model as seen in Figure 7. These attributes and relationships define the structure and content of the model, ranging from global identifiers to associations with other elements. They provide a structured framework for representing sensor-related data in construction and IoT domains.

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Figure 7:OntoGraf visualisation of the IfcSensor Attributes (shaded portion)

Table 5: IfcSensor Attributes

|  |  |
| --- | --- |
| IfcSensor Attributes | Type |
| ifcRoot | *“IfcRoot is the most abstract and root class for all entity definitions that roots in the kernel or in subsequent layers of the IFC specification. It is therefore the common supertype of all IFC entities, beside those defined in an IFC resource schema. All entities that are subtypes of IfcRoot can be used independently, whereas resource schema entities, that are not subtypes of IfcRoot, are not supposed to be independent entities.”* |
| IfcObjectDefinition | *“An*IfcObjectDefinition*is the generalisation of any semantically treated thing or process, either being a type or an occurrence. Object definitions can be named, using the inherited*Name*attribute, which should be a user recognisable label for the object occurrence. Further explanations to the object can be given using the inherited*Description*attribute.”* |
| IfcObject | “An IfcObject is the generalisation of any semantically treated thing or process. Objects are things as they appear - i.e. occurrences.” |
| IfcProduct | “The IfcProduct is an abstract representation of any object that relates to a geometric or spatial context. An IfcProduct occurs at a specific location in space if it has a geometric representation assigned. It can be placed relatively to other products, but ultimately relative to the project coordinate system.” |
| IfcElement | “An element is a generalisation of all components that make up a facility.” |
| IfcDistributionElement | “IfcDistributionElement is a generalisation of all elements that participate in a distribution system.” |
| IfcDistributionControlElement | “The distribution element IfcDistributionControlElement defines occurrence elements of a building automation control system that are used to impart control over elements of a distribution system.” |

**4.1.2.2 IfcSensor Properties** *(How do I look and what are my characteristics)*

From Table Based on different types of Sensors- General properties apply to all sensors but there are other specific sensor properties. IfcSensor Properties encompass a wide range of property sets and relationships for sensor models within the IFC framework. These properties include general and specific sensor characteristics, such as condition, electrical attributes, environmental factors, maintenance strategies, and warranty information. The relationships define the context and placement of sensor elements.

Table 5: IfcSensor Properties

|  |  |
| --- | --- |
| **Property Sets** | **Descriptions** |
| Pset\_Condition | 'Determines the state or condition of an element at a particular point in time.' |
| Pset\_ConstructionAdministration | 'Properties for Construction Administration. Often used for facility and asset management.' |
| Pset\_ElectricalDeviceCommon | 'A collection of properties that are commonly used by electrical device types.' |
| Pset\_ElectricalDeviceCompliance | 'Properties related to information about compliance to standards or regulations of electric devices.' |
| Pset\_ElementKinematics | 'Information confirming that the element has cyclic and/or pathed kinematic behavior. The resulting envelope may be available as a 'clearance' shape representation.' |
| Pset\_EnergyRequirements | 'Property set for the application of energy requirements to facility and physical elements.' |
| Pset\_EnvironmentalCondition | 'Properties defining environment conditions required by the element.' |
| Pset\_EnvironmentalEmissions | 'Property set for the application of energy emissions produced by facility and physical elements.' |
| Pset\_EnvironmentalImpactIndicators | 'Environmental impact indicators are related to a given “functional unit” (ISO 14040 concept). An example of a functional unit is a "Double glazing window with PVC frame" and the unit to consider is "one square meter of opening elements filled by this product”. Indicators values are valid for the whole life cycle or only a specific phase (see LifeCyclePhase property). Values of all the indicators are expressed per year according to the expected service life. The first five properties capture the characteristics of the functional unit. The following properties are related to environmental indicators. There is a consensus agreement internationally for the first five. The last ones are not yet fully and formally agreed at the international level.' |
| Pset\_EnvironmentalImpactValues | 'The following properties capture environmental impact values of an element. They correspond to the indicators defined into Pset\_EnvironmentalImpactIndicators. Environmental impact values are obtained by multiplying indicator value per unit by the relevant quantity of the element.' |
| Pset\_MaintenanceStrategy | 'Property set for the association of a maintenance strategy to an element, asset, or system.' |
| Pset\_MaintenanceTriggerCondition | 'Trigger levels for an asset that has an inspection-based maintenance strategy.' |
| Pset\_MaintenanceTriggerDuration | 'Trigger levels for an asset that has a PPM-based maintenance strategy.' |
| Pset\_MaintenanceTriggerPerformance | 'Properties for performance-based maintenance policies.' |
| Pset\_ManufacturerTypeInformation | 'Defines characteristics of types (ranges) of manufactured products that may be given by the manufacturer. Note that the term 'manufactured' may also be used to refer to products that are supplied and identified by the supplier or that are assembled off-site by a third-party provider. HISTORY: This property set replaces the entity IfcManufacturerInformation from previous IFC releases. IFC 2x4: AssemblyPlace property added.' |
| Pset\_Risk | 'An indication of exposure to mischance, peril, menace, hazard, or loss. Documentation of a potential hazard, likelihood, and consequence aligned with AS/NZS 4360 and BS PAS 1192-6:2017, which can be assigned to or associated with a product, activity, and/or location. Alternatively, it may be assigned to an ISO 3864 annotation symbol.' |
| Pset\_SensorTypeCommon | “Sensor type common attributes” |
| Pset\_ServiceLife | 'Captures the period of time that an artifact will last. HISTORY: Introduced in IFC2X4 as replacement for IfcServiceLife.' |
| Pset\_Tolerance | 'Properties express the tolerance relating to locating and shaping of an intended element or feature. Range diameters are non-negative describing a linear, rectangular, or boxed region.' |
| Pset\_Uncertainty | 'Property set capturing the geometric uncertainty regarding measurements including how the way that uncertainty was assessed.' |
| Pset\_Warranty | 'An assurance given by the seller or provider of an artifact that the artifact is without defects and will operate as described for a defined period without failure and that if a defect does arise during that time, that it will be corrected by the seller or provider.' |
| Qto\_SensorBaseQuantities | 'Base quantities that are common to the definition of all occurrences of sensor.' |
| Pset\_SensorPHistory | 'Properties for the history of controller values. HISTORY: Added in IFC4.' |

**4.1.2.3 IfcSensor Relations** *(Which objects are my parents and Children?)*

From Table 6 IfcSensor Relations involve key relationships that define the context and type of sensor objects within the IFC framework. These relationships determine where sensors are located, their geometric Representation, and how they relate to other objects, ultimately specifying their role and context.

Table 6: IfcSensor Relations

|  |  |
| --- | --- |
| ` Relations | Description |
| IfcBuildingControlsDomain | Found in the Domain layer |
| IfcSensorTypeEnum | The IfcSensorTypeEnum defines the range of different types of sensor that can be specified. |
| IfcSensorType | - Entity is a subtype of IfcProduct. It is an abstract representation of any object that relates to a geometric or spatial context. An IfcProduct occurs at a specific location in space if it has a geometric representation assigned. It can be placed relatively to other products, but ultimately relative to the project coordinate system. |
| IfcObjectPlacement | - Attribute that establishes the coordinate system in which all points and directions used by the geometric representation items under Representation are founded. - The Representation is provided by an IfcProductDefinitionShape, which can be either a geometric shape representation or a topology representation (with or without underlying geometry of the topological items). |

**4.1.2.4 IfcSensor Interactions** *(Which objects do I interact with?)*

IfcSensor Interactions, as illustrated in Figures 8 and 9, refer to the relationships and connections between IfcSensor entities and other elements within a building information modelling (BIM) context. These interactions include defining the type and properties of sensors, associating sensors with control objects, establishing connections to building elements, linking sensor ports for data exchange, and indicating how sensors provide services or Information related to a building. These interactions are crucial in modelling and managing sensor-based construction and building management systems.

A diagram of a network

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Figure 8:OntoGraf visualisation of the IfcSensor Interactions (shaded portion)

A diagram of a diagram

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Figure 9: Blow-out portion of the shaded portion of Figure 9.

From Table 7, the IfcSensor Interactions outline various entity definitions within the IFC data model, specifying relationships and associations relevant to sensor functionality. The IfcRelDefinesByType establishes a link between IfcSensorType and IfcSensor instances, defining the type and properties of sensors. IfcRelAssignsToControl associates sensors with control objects, regulating their behaviour or responding to measurements. IfcRelConnectsPortToElement connects sensors and building elements, indicating a physical or logical association. IfcRelConnectsPorts facilitates the exchange of data between sensor input and output ports. IfcRelServicesBuildings associates sensors with buildings, indicating their provision of services or Information related to the building.

Additionally, IfcProcedure and IfcTask capture device procedures and programs, while IfcPerformanceHistory documents the actual performance of sensors over time. IfcPropertySet and IfcPropertySetTemplate capture real-time device data and metadata about custom properties, respectively. IfcRelAssociatesClassification links devices and control points for unique identification within a control system.

Table 7: IfcSensor Interactions

|  |  |
| --- | --- |
| **IfcSensor Interactions** | **Entity Definition (Descriptions)** |
| IfcRelDefinesByType | “The objectified relationship IfcRelDefinesByType defines the relationship between an object type and object occurrences. The IfcRelDefinesByType is a 1-to-N relationship, as it allows for the assignment of one type information to a single or to many objects. Those objects then share the same object type, and the property sets and properties assigned to the object type.” |
| IfcRelAssignsToControl | “The objectified relationship IfcRelAssignsToControl handles the assignment of a control (represented by subtypes of IfcControl) to other objects (represented by subtypes of IfcObject, with the exception of controls).” |
| IfcRelConnectsPortToElement | *“defines the relationship that is made between a port and the IfcElement in which it is contained. It is a 1 to 1 relationship. Ports contained in different elements are connected to each other using the IfcRelConnectsPorts relationship. Using both relationships, a topological system can be defined.”* |
| IfcRelConnectsPorts | *“Defines the relationship that is made between two ports at their point of connection. It may include the connection geometry between two ports.”* |
| IfcRelServicesBuildings | *“An objectified relationship that defines the relationship between a system and the sites, buildings, storeys or spaces, it serves”.* |
| IfcProcedure | *“An IfcProcedure is a logical set of actions to be taken in response to an event or to cause an event to occur.”* |
| IfcTask | *“An IfcTask is an identifiable unit of work to be carried out in a construction project. A task is typically used to describe an activity for the construction or installation of products, but is not limited to these types”* |
| IfcPerformanceHistory | *“IfcPerformanceHistory is used to document the actual performance of an occurrence instance over time. It includes machine-measured data from building automation systems and human-specified data such as task and resource usage. The data may represent actual conditions, predictions, or simulations.”* |
| IfcPropertySet | *“The IfcPropertySet defines all dynamically extensible properties. The property set is a container class that holds properties within a property tree. These properties are interpreted according to their name attribute.”* |
| IfcPropertySetTemplate | *“IfcPropertySetTemplate defines the template for all dynamically extensible property sets represented by*[*IfcPropertySet*](https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD1/HTML/schema/ifckernel/lexical/ifcpropertyset.htm)*”* |
| IfcRelAssociatesClassification | *“This objectified relationship (IfcRelAssociatesClassification) handles the assignment of a classification object (items of the select IfcClassificationSelect) to objects (subtypes of IfcObject).”* |

**4.1.2.4 IfcSensor Geometry** *(What are my dimensions and defaults?)*

The geometric Representation of *IfcSensor* is given by the *IfcProductDefinitionShape*, allowing multiple geometric representations. IfcProductDefinitionShape is crucial in structuring and organising geometric Information associated with different types of products within the IFC framework. The IfcProductDefinitionShape is a component within the IFC data model designed to consolidate shape-related Information for an IfcProduct. It is a versatile container, accommodating geometric representations such as 3D solids and 2D annotations. This consolidation includes the management of associated presentation attributes. The IfcProductDefinitionShape enables the incorporation of multiple representations, allowing for the Representation of topological elements like vertices, edges, and faces, supplemented by optional geometric representation items. Additionally, these representations can be assigned to specific presentation layers, providing control over their visibility.

* + 1. **Establishing Correspondence between IfcSensor and saref:Sensor**

From Table 8 and Figure 9, in the mapping between saref:Sensor properties and IfcSensor properties, several critical correspondences and differences are identified. Notably, properties like saref:hasTimestamp, saref:hasSensingRange, and saref:hasValue do not find direct matches in the IfcSensor properties. However, saref:hasSensorType, saref:hasManufacturer, saref:measuresProperty, and saref:SensingFunction align with Pset\_SensorTypeCommon, Pset\_ManufacturerTypeInformation, Pset\_EnvironmentalImpactValues, and Pset\_SensorTypeCommon in IfcSensor, respectively. Moreover, specific properties under saref:hasState in saref:Sensor find mappings with Pset\_Condition in IfcSensor. This mapping provides a structured overview of the relationships and divergences between the properties of saref:Sensor and IfcSensor, crucial for maintaining consistency and interoperability in sensor-related data within the built environment.

Table 8: Mappings between the saref:Sensor Properties and IfcSensor Properties.

|  |  |
| --- | --- |
| **Sare:Sensor Properties** | **IfcSensor Properties** |
| saref:hasTimestamp | N/A |
| saref:hasSensingRange | N/A |
| saref:hasSensorType | Pset\_SensorTypeCommon |
| saref:hasManufacturer | Pset\_ManufacturerTypeInformation |
| saref:measuresProperty | Pset\_EnvironmentalImpactValues |
| saref:hasValue | N/A |
| saref:SensingFunction | Pset\_SensorTypeCommon |
| saref:hasState | Pset\_Condition |
| N/A | Pset\_ConstructionAdministration |
| N/A | Pset\_ElectricalDeviceCommon |
| N/A | Pset\_ElectricalDeviceCompliance |
| N/A | Pset\_ElementKinematics |
| N/A | Pset\_EnergyRequirements |
| N/A | Pset\_EnvironmentalCondition |
| N/A | Pset\_EnvironmentalEmissions |
| N/A | Pset\_EnvironmentalImpactIndicators |
| N/A | Pset\_MaintenanceStrategy |
| N/A | Pset\_MaintenanceTriggerCondition |
| N/A | Pset\_MaintenanceTriggerDuration |
| N/A | Pset\_MaintenanceTriggerPerformance |
| N/A | Pset\_Risk |
| N/A | Pset\_ServiceLife |
| N/A | Pset\_Tolerance |
| N/A | Pset\_Uncertainty |
| saref:hasManufacturer | Pset\_Warranty |
| N/A | Qto\_SensorBaseQuantities |
| N/A | Pset\_SensorPHistory |

A diagram of a property

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Figure 9: Main Mappings between the saref:Sensor Properties and IfcSensor Properties.

Several correspondences and distinctions are evident in the mapping between SAREF:Sensor interactions and IfcSensor interactions. Notably, saref:hasFunction aligns with IfcProcedure, indicating a correlation between the functional aspects of a sensor in SAREF and procedural definitions in IfcSensor. Similarly, saref:hasProfile finds a counterpart in IfcPropertySetTemplate, suggesting a link between sensor profiles and property set templates. Additionally, saref:offers in SAREF:Sensor maps to IfcPropertySet, implying a connection between offered functionalities and property sets in IfcSensor. The saref:UnitOfMeasure and saref:isMeasuredIn correspond to IfcPropertySetTemplate, reflecting the measurement units associated with sensors. Furthermore, interactions like saref:makesMeasurement are reflected in IfcPropertySet, indicating the act of measurement in both schemas. The saref:accomplishes interaction corresponds to IfcTask, suggesting an alignment between the accomplishment of tasks and task definitions in both schemas.

Table 9: Mappings between the saref:Sensor interactions and IfcSensor interactions

|  |  |
| --- | --- |
| **SAREF:Sensor Interaction** | **IfcSensor Interaction** |
| saref:hasFunction | IfcProcedure |
| saref:hasProfile | IfcPropertySetTemplate |
| saref:offers | IfcPropertySet |
| saref:UnitOfMeasure | IfcPropertySetTemplate |
| saref:isMeasuredIn | IfcPropertySetTemplate |
| saref:makesMeasurement | IfcPropertySet |
| saref:accomplishes | IfcTask. |
| saref:consistsOf | IfcRelConnectsPorts |
| saref:controlsProperty | IfcRelDefinesByType |
| saref:isUsedFor | IfcRelServicesBuildings |
| N/A | IfcRelAssociatesClassification |
| N/A | IfcPerformanceHistory |
| N/A | IfcRelConnectsPortToElement |
| N/A | IfcRelAssignsToControl |
| N/A | IfcRelConnectsPortToElement |

However, several interactions in SAREF:Sensor do not have direct matches in IfcSensor, such as saref:consistsOf, saref:controlsProperty, saref:isUsedFor. This may signify unique aspects of sensor interactions in the SAREF model that might not be fully captured by the IfcSensor schema.

A diagram of a diagram

Description automatically generated with medium confidence

Figure 10 : Exact correspondence between the saref:Sensor interactions and IfcSensor interactions

Further analysis carried out scrutinised the properties and interactions of the Saref:Sensor and IfcSensor, aiming to bring forth both quantitative differentiation and commonalities embedded within these two distinct sensor models. Particularly Figure 11 and 12, illustrated the significance of the established classes within IfcSensor and saref:Sensor properties and interactions. Figure 11 illustrated the number of established properties and interactions of the sensor models.

Figure 11: Total Number 0f Sensor Properties And Interactions

Figure 12 presents the percentage-based alignment between the properties and interactions of the two sensor models. Specifically, in terms of properties, Saref:Sensor is found to be associated with 5 distinct properties that align with IfcSensor sensor data models. Transitioning to interactions, Saref:Sensor is completely mapped with all 7 IfcSensor data models, indicating a comprehensive alignment between the two regarding functional dynamics.

Figure 12: Exact correspondence between the saref:Sensor interactions and IfcSensor

* + 1. **Hosting semantic alignment between the IFC and SAREF sensor models results**

Hosting the IFC and SAREF sensor data models on GitHub offers numerous advantages. It ensures accessibility to a broad audience, facilitating easy viewing, downloading, and contribution to the development process. Collaborative opportunities abound on GitHub, enabling researchers, developers, and stakeholders to refine and improve the data models collectively. With Git's version control system, tracking changes becomes effortless, allowing for easy review of previous versions and facilitating transparency in the development process. GitHub's documentation tools, including README files and wikis, provide avenues for comprehensive documentation, ensuring clarity and usability for contributors. Hosting the sensor model results on GitHub is a cornerstone for collaborative, transparent, and efficient development in sensor data modelling.

* + 1. **Possible Practical Applications of the saref:Sensor and IfcSensor Alignment**

Since the results of the ifcsensor and saref:sensr data models have been aligned and deposited in the GitHub repository with the link in Table 10, it can be accessed for practical implementaitons in the built environment as indicated below;

* **Smart Building Design and Construction:** In the context of designing a sustainable office building, the alignment of saref:Sensor and IfcSensor introduces a transformative approach to architecture and construction. This alignment enables architects to seamlessly integrate sensor specifications directly into the Building Information Modeling (BIM) model. For instance, the strategic placement of temperature and occupancy sensors is informed by the digital model, dictating precise locations for data collection to optimize climate control and space utilization. This digital blueprint becomes an invaluable guide for construction workers, ensuring accurate sensor installations by design specifications.
* **Real-Time Monitoring and Energy Efficiency:** As the building transitions into operational mode, the alignment between saref:Sensor and IfcSensor facilitates real-time monitoring of crucial parameters such as temperature, energy consumption, and occupancy. This integrated data empowers building managers to dynamically optimize HVAC systems based on actual occupancy patterns, resulting in substantial energy savings. Deviations from expected values trigger alerts, enabling maintenance teams to swiftly locate and address issues with specific sensors, ensuring the entire building functions efficiently.
* **Responsive Building Automation:** In a scenario with motion sensors (saref:MotionSensor) and light sensors (saref:LightSensor), the alignment guarantees their accurate representation in the BIM model using corresponding IfcSensor entities. This synchronization enables building automation systems to dynamically respond to real-time data. Lights can adjust based on occupancy, and heating or cooling systems can adapt to the number of people in a space. This not only enhances user comfort but also significantly contributes to energy efficiency, aligning the building with modern sustainability standards.
* **Facility Management and Predictive Maintenance:** The alignment provides a vital link between physical building elements and their corresponding sensors, fostering predictive maintenance. Facility managers leverage historical data from IfcSensor entities to anticipate maintenance needs. For instance, consistent deviations reported by a sensor linked to an HVAC system can trigger a maintenance alert, allowing for proactive intervention before a major issue arises. This preventive maintenance approach ensures the long-term reliability and efficiency of building systems.
* **Data-Driven Decision Making:** By aligning saref:Sensor and IfcSensor, stakeholders throughout the building's lifecycle gain access to a unified platform for decision-making. Architects validate design assumptions with real-world sensor data, construction teams ensure accurate implementation, and facility managers make informed decisions for ongoing operation and maintenance. This cohesive approach enhances collaboration and efficiency at every stage, promoting a sustainable and technologically advanced building lifecycle**.**