Mapping of an abstract PLC information model into different fields of application

Björn Kämper [a], *Maximilian* Both [a], *Nicolai* Maisch [a], *Jochen* Müller [a]

[a] Institute of Building Services Engineering, TH Köln, University of Applied Sciences, Cologne, Germany, { bjoern_klaus.kaemper; maximilian_alexander.both; nicolai.maisch; jochen.mueller}@th-koeln.de.

Abstract. Collaborative working in BIM applications requires that different users have a common understanding of components such as pumps, valves or pipes. This common understanding is achieved by describing components through information models composed of defined properties. The different roles involved in the planning process (manufacturer, planner, operator) have different views of components. To avoid that different roles, develop specific information models, it makes sense to develop common information models describing the whole product life cycle (PLC). Besides BIM applications, information modeling of components is an area that is also used in industrial applications. An abstract modeling approach helps to ensure that information models are not developed in a technology-specific way.
This paper describes how a manufacturer- and technology-independent PLC information model for pumps and vacuum pumps was developed and subsequently integrated into industrial services and building services information standards. The integration is intended to serve as the basis for a continuous flow of information over the life cycle of pumps in building services applications. The challenges of this work include mapping an abstract modeling concept to existing semantics in different technologies and not creating duplicates in existing data standards.

Keywords. Industrie 4.0, cross-lifecycle information model, semantic description, BIM
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1. Introduction

The term "Industry 4.0" describes the progressive digitization and networking of systems in value chains. The core idea of the fourth industrial revolution is that systems exchange information independently and networked, thereby optimizing processes. Even if the term "Industry 4.0" (I4.0) is today more associated with the manufacturing/production phase of assets, there are also approaches that assume that the concepts of I4.0 have an impact on the entire life cycle of an asset [1] [2].
An asset passes through different phases in its life cycle and comes into contact with a wide variety of systems and economic sectors. A pump, for example, already has information stored for integration into planning software as well as information for control in building automation. The different definitions of properties and functions make it difficult to implement self-organizing systems today. An example is given in Fig. 1. Assets from different manufcaturer should be integrated in an application for energy management. Different semantics (here namingconventions and physical unnit) lead to manual effort.

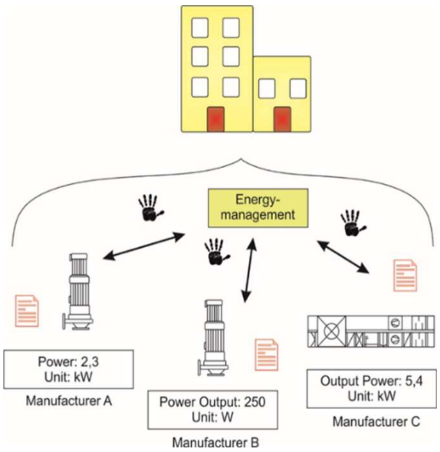

Fig. 1 - Different semantics complicate the integration effort of assets in applications (in this case an automation system).

In order for assets to be able to interact automatically and with minimal manual integration effort with the systems relevant for the respective lifecycle phases in the future, information for assets should be standardized. In order to be able to exchange information between systems in different lifecycle phases in the future (e.g., between a BIM-based planning software and an energy management application), information should not be developed for a single technology or a single use case, but rather in an abstract and cross-lifecycle manner. Fig. 2 shows different life cycle phases of assets according to IEC 62890.

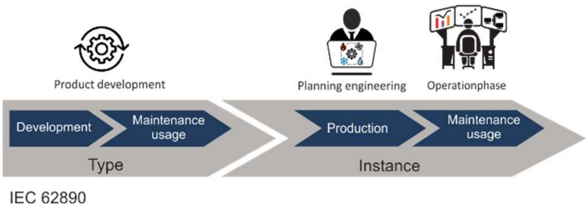

Fig. 2 - Assignment of life cycle processes according to IEC 62890 to application fields

In a common project between the Cologne University of Applied Sciences and the VDMA trade associations Pumps + Systems and Compressors, Compressed Air and Vacuum Technology, more than 500 pump-specific and lifecycle-describing properties were derived from national and international standards. These properties were summarized in process- and life-cycle-oriented *Submodels* and mapped onto the abstract information model of the *Asset Administration Shell* (AAS) [3]. In further projects, this developed information model was implemented in specific domains and areas of use (see Fig. 3). By defining this information model as an OPC UA Companion Specification, a communication connection to the OPC UA communication protocol was made possible [4]. OPC UA is considered to be the future standard for industrial communication. By integrating the properties into the online repository ECLASS, the properties are available in the "Language 4.0" [5, 6]. ECLASS is a data standard that classifies products and describes them using ISO-compliant properties [6]. In order to be able to use the properties in the process flows of building equipment programs, it is necessary to calculate the properties in a role- and user-specific manner. In order to integrate the information model into the planning phase of building services engineering, the properties are integrated into BIM as role-specific views.

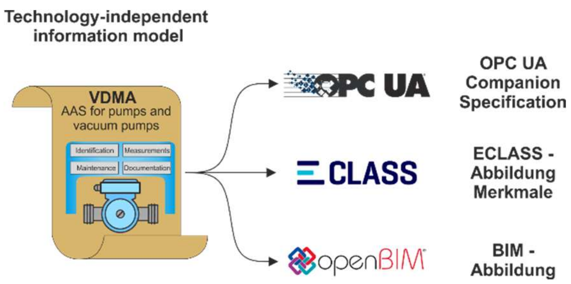

Fig. 3 - Derivation from abstract and independent information model into different domains / areas of use

The following chapters describe the path from the creation of an abstract information model to its implementation in the various technologies.

2. Asset Administration Shell for pumps and vacuum pumps

The "*Plattform Industrie 4.0*" was launched in 2013 by the German Federal Ministries for Economic Affairs and Energy and for Education and Research. A wide variety of companies and associations are organized in this platform with the aim of advancing the digital transformation in Germany. The *Plattform Industrie 4.0* develops technical solutions in various working groups, which are freely accessible via the platform [7]. The *Plattform Industrie 4.0* has defined the term *Industrie 4.0 Component* as a "globally uniquely identifiable participant with communication capability consisting of AAS and asset" [8]. Such an *AAS for pumps and vacuum pumps* was developed as an abstract information model.

2.1 Structure of Asset Administration Shells

The asset is defined by *Plattform Industrie 4.0* as "Everything that requires a *connection* for an Industry 4.0 solution: Machines and, if applicable, their components; supplier material and products; documents that are exchanged (plans, orders); contracts; purchase orders;..." [8]. Thus, an asset can be both a non-physical file and a physical product.

According to *Plattform Industrie 4.0*, the AAS is the implementation of the "digital twin" [7]. This digital image represents information and properties of an asset. AASs can contain information about the entire life cycle of an asset. Information is divided into *Submodels*. A *Submodels* can be described as a group of features that describes a particular aspect of an asset. Figure 4 shows an asset administration shell that has two *Submodels* "Measurements" and "Design" assigned to it. In the "Measurements" *Submodel* are properties that represent current measurements of the asset (e.g. speed or fluid temperature). *Submodels* can contain any number of properties.

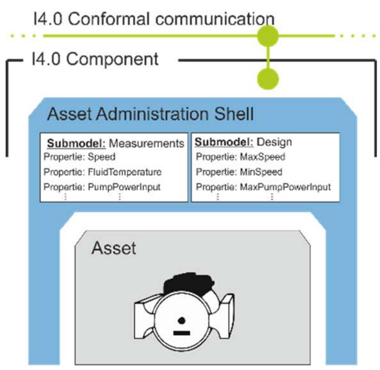

Fig. 4 - I4.0 - Component consisting of asset and AAS consisting of two Submodels with corresponding properties

2.2 Defining Submodels for pumps and vacuum pumps

The process of creating the *Submodels* for pumps and vacuum pumps can be described in three steps (see Fig. 5). First, use cases were defined together with the association companies that are to be realized with the *Submodels* to be developed. In the next step, properties were derived from national and international standards with which the corresponding use cases can be mapped. In the last step, the properties derived from the standards were divided into corresponding *Submodels*.

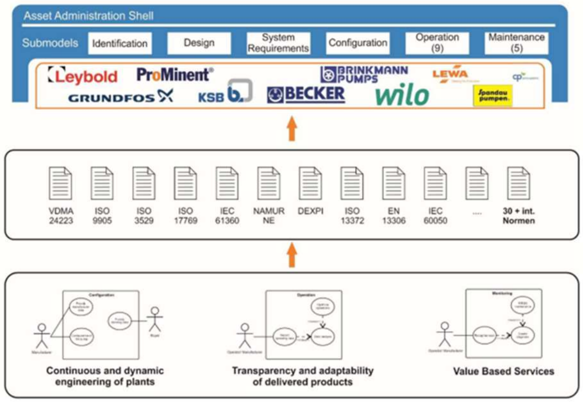

Fig. 5 - Procedure for deriving the Submodels for pumps and vacuum pumps

- ***Use-Case 1:***
  Continuous and dynamic engineering of plants (short form: Configuration)
  This use case is used to deliver a preconfigured device to the operator / integrator. The basis for this is the manufacturer data of the asset and the data of the operator / integrator about the process in which the asset is to be used. On this basis, a device is configured by the manufacturer so that the correct operating points are preset, and it can be put into operation.

- ***Use-Case 2:***
  Transparency and adaptability of delivered products (short form: Operation)
  An Operator / integrator should be able to measure and archive the operating data of the asset. It should also be possible to control the asset remotely.
  For the operator´s / integrator´s process monitoring, the device provides access to standardized alarms, warnings and events.
  In combination with the information of the use case configuration, the device operation can be analyzed and optimized. A subsequent reconfiguration of the device can be realized in order to adapt it optimally to the requirements of the operation.

- ***Use-Case 3:***
  Value based services (short form: Maintenance)
  For integrating a device in the operator´s Maintenance Management application, the device provides a common set of properties representing different maintenance strategies. Properties for breakdown, preventive and condition-based are available – depending on the maintenance strategy assigned to the asset within the operator´s maintenance process.

  Based on unique asset identification, an operator / integrator requires device related documents. Properties should contain a file or link to e.g. P&I diagrams, wiring diagrams, manuals or spare parts lists for the respective asset.
  The wear of the device is observed during operation and diagnostic information about the current state of the device is generated.

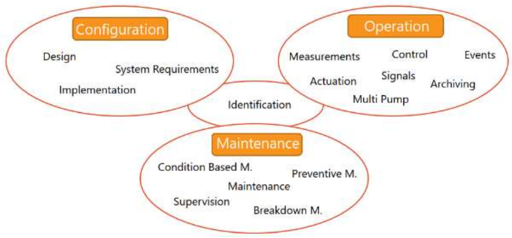

Fig. 6 - The derived Submodels with assignment to the corresponding use cases.

As shown in figure 6, a *Submodel* "Identification" has been defined. The *Submodel* Identification forms the basis for the operation of an asset and the operators Plant Asset Management, e.g. Documentation Management, Energy Management and Maintenance Management. Since this *Submodel* is so general, it was not assigned to a separate use case but as part of each use case.

In total, more than 500 life cycle describing properties for pumps and vacuum pumps were classified into 18 *Submodels*. As can be seen in table 1, the properties were defined according to IEC 61360 (Standard data element types with associated classification scheme – see table 1). The defined *Submodels* were deposited with the VDMA Association for Pumps and Vacuum Pumps for the following work as an interim report.

Tab. 1 - Exemplary representation of an IEC 61360 compliant attribute

Attribute	Pump power input
Identifier	0173-1#02-ABC172#001
Version number	-
Change number	-
Preferred name	Pump power input
Formula symbol	P_op
Definition	Measured power transmitted to the pump by its driver
Data type	REAL_MEASURE
Value format	NR2..3.3
Class of the properties	K27
Unit of measurement	Watt
Short name	P_{op}
Source document	DIN EN ISO 17769-1

3. Mapping in ECLASS

ECLASS is an ISO/IEC-compliant data standard that enables products and services to be described uniquely. This enables a standardized digital data exchange between different organizations even if they are located in different language areas. In ECLASS, more than 19,000 properties are organized in over 42500 classes. Each property is assigned a unique ID in ECLASS [9]. Such an identifier can be seen for example in table 1 in the first row.

The integration into ECLASS was done to have the developed properties defined globally unique in an online repository and to link them with a globally unique identifier.

3.1 Structure of ECLASS

The ECLASS data standard is based on a four-level hierarchy. At the lowest level (*Commodity classes*), ECLASS provides the property lists. In these properties lists, the product-specific properties can be assigned to the different classes. The four-level hierarchy is shown in Fig. 7.

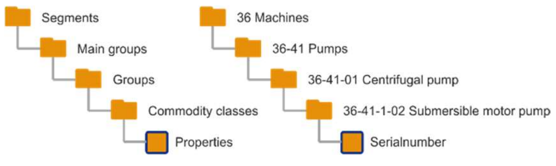

Fig. 7 - Structure of the hierarchy levels in ECLASS with representation of a submersible motor pump.

As can be seen in figure 7, in ECLASS properties are only added to the lowest hierarchy level. Properties that describe a pump in general (e.g. "pump type") cannot be assigned to the main group and thus inherited by the subordinate hierarchies.

In ECLASS there are two different modeling approaches: *Basic* and *Advanced*. In ECLASS *Basic*, properties can only be assigned to the corresponding *Commodity classes* as a flat list. ECLASS *Advanced* was integrated with Release 7.0 (currently ECLASS Release 12.0), providing extended modeling capabilities. Among other things the *Aspect* was introduced by ECLASS *Advanced*. An *Aspect* allows to bundle single properties and to assign these bundled *Aspects* to *Commodity classes*. Figure 8 shows this at the example of two properties "SerialNumber" and "MinmumSpeed". While the proeprties in ECLASS Basic are arranged as a flat list, in ECLASS Advanced it is possible to sort the properties according to their topic.

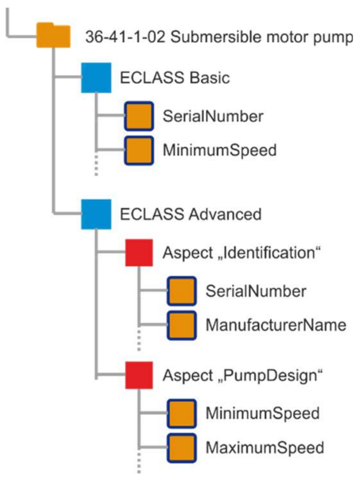

Fig. 8 - Comparison of ECLASS Basic to ECLASS Advanced.

Due to the possibility of assigning arbitrary properties to *Aspects* and then assigning these *Aspects* to any number of classification classes, this modeling approach is suitable for modeling *I4.0-Submodels* in ECLASS.

3.2 Modelling of ECLASS Aspects for Pumps & Vacuum pumps

In the first step of the integration of the *I4.0-Submodels* for pumps and vacuum pumps, all attributes contained in the *Submodels* had to be integrated into ECLASS. In ECLASS, each attribute may only occur once. Before a property from the *Submodels* was integrated into the ECLASS platform, it had to be checked whether this property was already described in ECLASS in order to avoid a duplicate.
After the integration of all properties, the properties were bundled into *Aspects* according to the *Submodels*. Again, it had to be considered that no existing *Aspect* is duplicated in ECLASS. This is especially true for the ECLASS *Aspect* "Identification". In ECLASS there are *Aspects* that are mandatory assigned to each *Commodity class*. These *Aspects* contain properties which are generally valid and not product specific. One of these mandatory *Aspects* is the *Aspect* "Identification". This *Aspect* contains properties of the manufacturer (e.g.: manufacturer name, article

number...) and properties of the supplier (e.g.: supplier name, delivery time). In this already existing ECLASS *Aspect* many properties are contained which are also contained in the Submodel "Identification". In order to avoid a duplicate, but still to be able to take over all properties from the *Submodels* in ECLASS, an ECLASS *Aspect* "PumpIdentification" was created. In this *Aspect* all properties are available which deal with identification properties but are not mapped in the general ECLASS *Aspect* "*Identification*".

The contents of the *Submodels* were developed for different pump types (liquid pumps, vacuum pumps...) and thus contain both pump-general properties and properties for specific pump types. To ensure that a liquid pump does not support the same properties as a vacuum pump when all *Submodels* are integrated, different *Aspect*s had to be created for the different pump types.

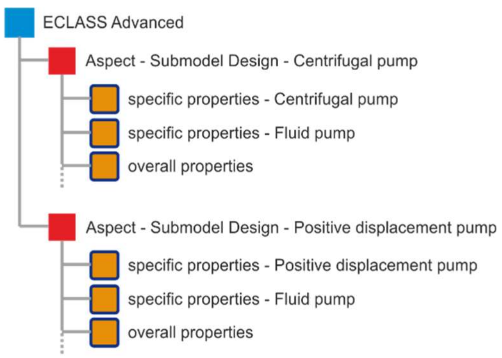

Fig. 9 - The Submodel Design divides into ECLASS-Aspects for centrifugal pumps and positive displacement pumps.

Figure 9 shows this type of modeling. For the "Design" submodel, two different *Aspects* were defined for centrifugal pumps and positive displacement pumps. In both *Aspects*, generally valid properties and properties for liquid pumps are stored. However, the two *Aspects* differ according to the specific properties for centrifugal pumps and positive displacement pumps.

4. Mapping in OPC UA

OPC UA (Open Platform Communications Unified Architecture) is a platform-independent communication protocol which is regarded as the new de facto standard in industrial automation [10]. Compared to the predecessor protocol of the OPC Foundation (OPC DA - Data Access), it is not only possible in OPC UA to transport machine data, but also to describe machine data semantically. Such semantic descriptions are developed as Companion Specifications by associations and made available by the OPC UA Foundation. In OPC UA servers, the objects, methods and attributes of the Companion Specifications can be mapped and instantiated in an object-oriented manner.

4.1 Structure of an OPC UA Server

OPC UA servers follow a layered structure (Figure 10).

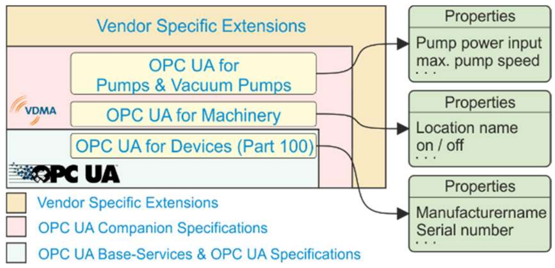

Fig. 10 - Graphical representation of an OPC UA server structure with consideration of different specifications

In the lowest layer, the basic services for information modeling and data exchange are organized. Thus, these services are available in every OPC UA server [11]. In addition to the basic services, the OPC Foundation Foundation also develops its own specifications that deal with general functions and attributes. Figure 10 shows *OPC UA for Devices (Part100)* as one such specification [12]. In this specification, general attributes of devices (e.g., manufacturer name or serial number) are organized. These generalized specifications enable client applications to program an OPC UA server in such a way that it can read out the manufacturer names and serial numbers of all devices, regardless of what kind of device they are. For this reason, it is recommended to base all companion specifications that represent devices on the general specification of the OPC Foundation [12].
In the middle layer of Figure 10, the semantic descriptions are stored in the form of OPC UA Companion Specifications that are drafted by professional associations (such as the VDMA in this example) for individual machine types. In addition to these machine-specific specifications, there are also specifications in this layer that deal with generalized functions and attributes. The specification *OPC UA for Machinery* [13] contains attributes and methods that extend the specification *OPC UA for Devices (Part 100).*
The specification for pumps and vacuum pumps is also based on this specification and can also be seen in the middle level of Figure 10. More about the modeling in the next chapter.
The top level of Figure 10 shows the possibility for manufacturers and users to develop their own specifications independently or based on specifications drafted by trade associations.

4.1 Modelling of OPC UA Companion Specification for Pumps & Vacuum pumps

The designed *Submodels* of the *AAS for Pumps and Vacuum pumps* were converted into an OPC UA Companion Specification in a joint working group of the Cologne University of Applied Sciences and the VDMA trade association for Pumps + Vacuum pumps [4]. This comprehensive specification contains all attributes from the *Submodels*. The only attributes that are mandatory are the attributes that are marked as mandatory by *OPC UA for Devices (Part 100)* and *OPC UA for Machiner.*

As a working group under the umbrella of the VDMA, the mapping was done considering the general VDMA specification *OPC UA for Machinery* and thus also the general OPC UA *specification OPC UA for Devices (Part 100).*
Figure 11 shows the modeling of the *Submodels* in an OPC UA server structure with consideration of the modeling rules and attributes from *OPC UA for Machinery* and *OPC UA for Devices (Part 100)*. In the figure, all objects are preceded by leading numbers that indicate the specification from which the corresponding objects originate.

- Leading 0: OPC UA Base-Services
- Leading 1: *OPC UA for Devices (Part 100)*
- Leading 2: *OPC UA for Machinery*
- Leading 3: *OPC UA for Pumps and Vacuum Pumps*

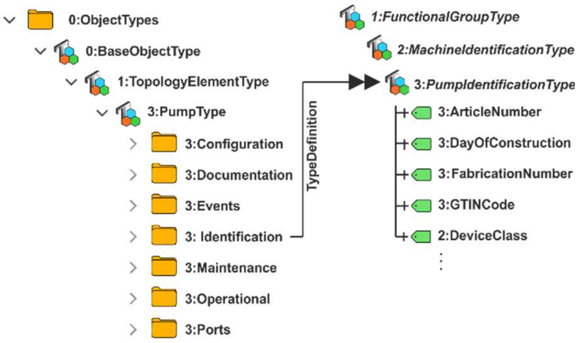

Fig. 11 - Nodestructure of OPC UA Companion Specification for Pumps and Vacuum pumps

As can be seen in the figure 12, the *Submodels* are arranged under a PumpType. The "Identification" Submodel shown here as an example in more detail shows how the modeling was implemented considering *OPC UA for Machinery* and *OPC UA for Devices (Part 100)*.

In *OPC UA for Machinery*, there is already a *MachineIdentificationType* that contains many attributes that are also contained in the *Submodel* "Identification" from the *AAS for Pumps and Vacuum Pumps*. Here, when transferring the attributes from the *Submodels* to the Companion Specification, it had to be considered which attributes are already available and which attributes have to be supplemented, just as with ECLASS. In the figure 12 this is to be recognized at the attribute "*2: DeviceClass*". This attribute was defined in the *Identifiaction* part model as well as in *OPC UA for Machinery*, which is why it was not defined again in the OPC UA Companion Specification for Pumps and Vacuum Pumps, but inherited (recognizable by the leading 2 instead of a leading 3).

All *Submodels* have been modeled in the OPC UA Companion Specification for Pumps and Vacuum Pumps as subtypes of the *FunctionalGroupType* defined in *OPC UA for Devices (Part 100).* The *FunctionalGroupType* is defined as: "*FunctionalGroups* are used to structure Nodes like Properties, Parameters and Methods according to their application such as configuration, diagnostics, asset management, condition monitoring and others.".

4.2 OPC UA Companion Specification referring to online dictionaries

In [14] it is defined that objects in OPC UA can reference online dictionaries as ECLASS. Each object can be assigned a reference in which the globally unique identifier is arranged that refers to the corresponding repository. This enables OPC UA client applications to search for attributes in OPC UA servers that are linked to corresponding entries in an online repository.
Since the attributes integrated in the online dictionary ECLASS are consistent with the attributes integrated in the OPC UA Companion Specification for Pumps and Vacuum Pumps, this referencing can be implemented in this Companion Specification. However, due to different release dates, this was not done in the first version of the OPC UA Companion Specification for Pumps and Vacuum Pumps.

5. Mapping in BIM

In technical building equipment, different actors/roles work integrally with each other in the planning and operating processes. Today, Building Information Modeling (BIM) is used as a planning method in large-scale projects.
Programs that supports BIM work with the standardized data format IFC, which is managed by BuildingSmart [15].

5.1 Structure of BIM

In order to be able to semantically describe attributes and products in an IFC-Model and to exchange them in a standardized way, the attributes that can be used in BIM are structured in the bSDD (building Smart Data Dictionary) and managed by the building Smart organization [15]. In order to make the contents of the *Submodels* accessible for BIM, the properties from the *Submodels* are integrated into the bSDD (see fig. 12). Just as in ECLASS and OPC UA, duplicates must be prevented here.

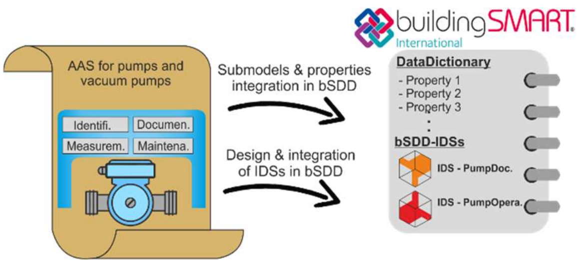

Fig. 12 - Transfer of the contents of Submodels into bSDD as attributes and Information Delivery Specifications

In addition to attributes, *Information Delivery*

Specifictaions (IDS) are also defined in the bSDD. IDS will find their way into the BIM world with the major release of IFC5.0.
With the help of an IDS, specific attributes can be retrieved from an existing and extensive IFC file (see fig. 13).

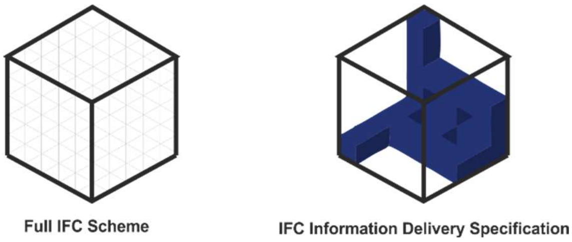

Fig. 13 - IDS allow to export a reduced set of attributes from an existing IFC Model for a common building.

IDSs thus define a role-specific perspective (view) on a building [16]. This prevents, for example, that role-specific applications have to process information that is not of interest for the specific application.

In BIM, a concept is already used in the current IFC versions to obtain role-specific information from a common IFC file. *Model View Definitions* (MVDs) allow the different actors/roles in the design and operation process (architects, building services engineers, etc.) to export a trade-specific model (architecture, HVAC) from the common IFC model and use it in specific software applications. IDS will replace MVDs and allow such specific views to be applied not only at the trade level, but also at the component level [17].

5.2 Role-specific expression of Submodels

Roles involved in building construction and operation processes are derived from existing HVAC design and operation processes. The *Submodels* for pumps and vacuum pumps are then assigned to the individual roles. The assigned *Submodels* are then transferred into IDSs and integrated into the bSDD.
By integrating machine-specific and role-specific IDSs into the world of BIM, it will be possible in the future to develop programs for building services engineering that deal with specific life cycle phases of a pump. The different roles from the planning and operating processes of building services engineering can have only those attributes specifically displayed from the entire IFC file that are of interest to the respective role (see fig. 14).

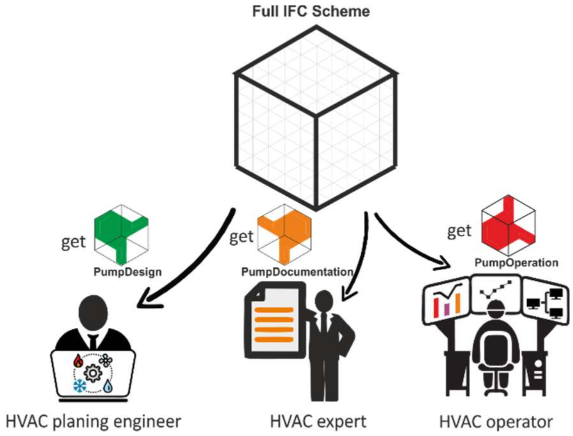

Fig. 14 - Different roles interacting with the IFC model over the life cycle of a building can export specific attributes for the respective use case through IDS.

6. Summary

This paper described how an abstract and cross-lifecycle information model was developed for an asset. This information model was mapped to the modeling rules of the *Asset Administration Shell* developed by *Plattform Industrie 4.0*. Even though there are different approaches to develop an executable technology from the AAS [18, 19], in this project the AAS was mainly used as a technology-independent and thus abstract information model for modeling. Based on this abstract information model, the content was transferred into three different application areas. As a communication mapping, the contents were transferred into an OPC UA Companion Specificication, which was published in May 2021 [4]. In ECLASS, the content was published with MAJOR Release 12.0 in November 2021. The mapping of the content in the bSDD and the creation of the *Information Delivery Specifications* will be completed by September 2022.
When transferring the content to the different technologies, the biggest workload is to review the existing content to avoid duplicates. Another difficulty arises from the different modeling capabilities. While in OPC UA object-oriented modeling approaches can be used, in ECLASS only the classes on the lowest hierarchical level are provided with properties.
The goal of this work is to develop a cross-lifecycle and technology-independent understanding of the semantic description for a single component (in this case a pump). This semantically uniform description can enable applications to exchange information about the component with other applications outside their own value chain.

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