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INTERNATIONAL ELECTROTECHNICAL COMMISSION

International Standardization Activity: Digital Factory Framework

1 Introduction

Today's economy calls for fast and flexible production of products with small batch sizes – down to a batch size of "one." This means that production systems have to be flexible and support many different variations of a product or many different products – Smart Manufacturing is considered as a solution to these requirements.

The base of smart manufacturing is digitalization. In smart manufacturing, which has begun to progress in various ways, the digital representation of the production system is fundamental. Digitalizing the entire life cycle of the production system – covering design, construction, installation, operation, maintenance, and retirement – enables related departments and enterprises to share the latest and accurate information about the production system and its operation.

Until now, such information has been distributed in different forms of documents like drawings, lists and data sheets. Even if these documents have been digitalized, this approach has challenges: information is fragmented such as stored in different data formats used by different engineering tools depending on the situation, the information is represented in different structures and it is identified differently (e.g. using different denominations for the same assets or for the same data points). This conventional approach requires re-input and conversion of information when using it in different engineering tools, and the latest information updated in one engineering tool is not automatically reflected in the same data in another engineering tool, see Figure 1.

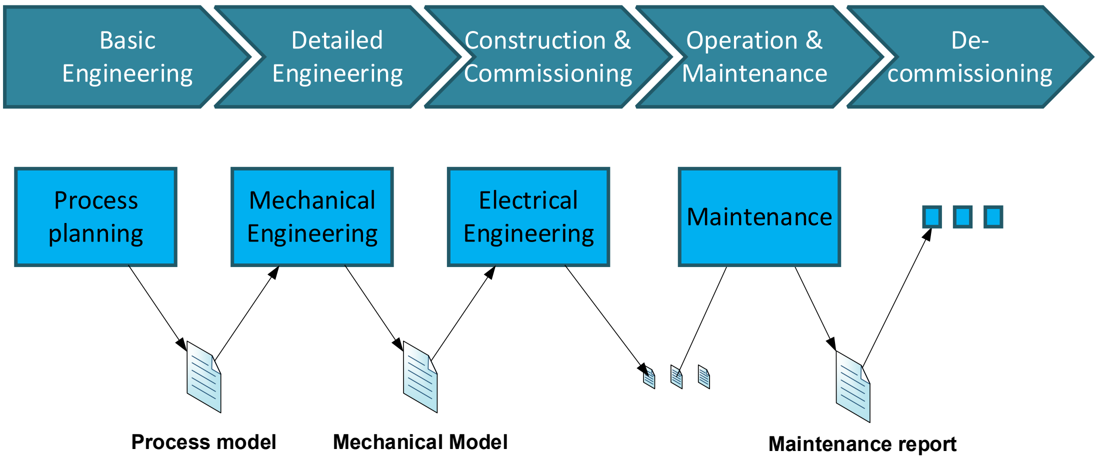

Figure 1 – Various engineering tools in the system life cycle

The Digital Factory framework (hereinafter referred to as "DF framework"), which is under development by IEC TC 65/WG 16 Digital Factory, is an international standard numbered IEC 62832 addressing such challenges by providing a common reference for digitization of data related to production systems. The standard is defining common rules for utilizing data based on dictionaries.

A data dictionary consists of computer-understandable data attributes and classifications as its basic elements and is known as Common Data Dictionary (CDD) in IEC, eCl@ss®[1] dictionary or eOTD®[2]. A data dictionary in principle is an ontology providing a classification of assets and properties for describing these assets in a semantically unambiguous way. Those dictionaries originally were invented to provide product data and to support procurement of products. Companies use the definitions from dictionaries to provide standardized descriptions of their products, so that interested customers understand the characteristics of the product. Product data based on dictionaries provides semantically rich product descriptions. This approach supports comparison of the characteristics of different products and the matching of the characteristics of a product with the original requirements such that it can also be applied in system engineering workflows.

The DF framework defines rules for structuring data using data dictionaries (not limited to CDD) that meet certain requirements for citing the contents, but it does not define the data dictionaries themselves. The DF framework aims to construct a digital representation of the entire production system, called a Digital Factory, and to utilize the information widely in various situations.

Whereas many international standards related to the smart manufacturing and specifications based on them specify data dictionaries itself, or a system that includes system configuration, communication/information security, hardware/software implementation, DF framework is developed as a standard for integrating information beyond these systems. Its outline is explained in the following clauses.

2 Development history and latest trends

The development of the DF framework started in April 2011, when the call for international experts (65/478/AC) was conducted by the TC 65 chair and secretary (Figure 2). According to the document (65/477/DC) explaining the original ideas, which was circulated at the same time with the NP, the Digital Factory is a model of a method on how to represent plant structures electronically instead of with paper drawings and specifications. One year after starting the work in IEC TC 65 / WG 16, a new work item proposal (65/500/NP) and a draft Technical Report (65/499/DTR) were voted in March 2012. Both were approved. The TR was published as IEC TR 62794 ED1 in November of that year. Since the first edition was developed in the short-term based on the original proposal and contained many ambiguities and inconsistencies, its revision work was started immediately after its publication. After two rounds of Committee Draft review process (65/563/CD, 65/597/CD), a draft Technical Specification (65/629/DTS) was voted in July 2016, and published in November as a Technical Specification, IEC TS 62832-1 ED1.

The development of Part 2 and 3, that defines the model elements and their usage rules respectively, was started around the same time as the publication of IEC TS 62832-1 ED1 that outlines DF framework. After two rounds of Committee Draft review process for each, the Committee Drafts for Voting (65/774/CDV, 65/775/CDV) were internationally circulated and approved in November 2019. In parallel, the revision work for elevating IEC TS 62832-1 ED1 (Part 1) to the international standard (IS) was started to ensure consistency with Part 2 and 3, then its Committee Draft for Voting (65/766/CDV) was circulated and approved. All parts are going to be published as International Standards in January 2021.

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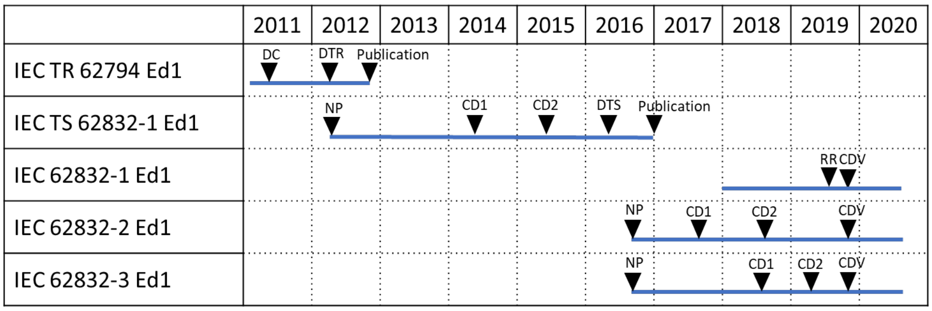

Figure 2 – Historical time chart

Terms "digital transformation" and "digital twin", which are used even in usual business scenes now, did not exist in 2011 when this project started. Although there isn't still a unified definition of digital twin, the Digital Factory can be interpreted as a framework corresponding to digital twin in a broad sense, and it is one of the most mature international standards of digital twin, with the longest history. Similarly, the concept of data dictionary and semantic interoperability, which is the basis of the DF framework, was generally not well recognized at the beginning of the development, but now it has drawn attention as one of the most important elements of the future international standards. This can be seen from the white paper entitled "Semantic interoperability: challenges in the digital transformation age" published by the IEC MSB (Market Strategy Board) in 2019. How to incorporate different international standards (IEC 61360 / ISO 13584-42 and ISO 22745) that specify data dictionaries that define product specifications was a major argument in the initial stage of the development. Nowadays their integration is proceeding by a joint working group between IEC SC3D and ISO TC184/SC4 (IEC SC3D/JWG1). It is also intended to target other data dictionaries such as ISO 15926.

Up to now, 31 face-to-face meetings and many remote meetings have been held in the nine (9) years since the project started.

3 Technology overview

3.1 Introduction

The fundamental idea of the DF framework is to use data dictionaries as a common base for identifying and for providing semantic information for engineering data, see Figure 3.

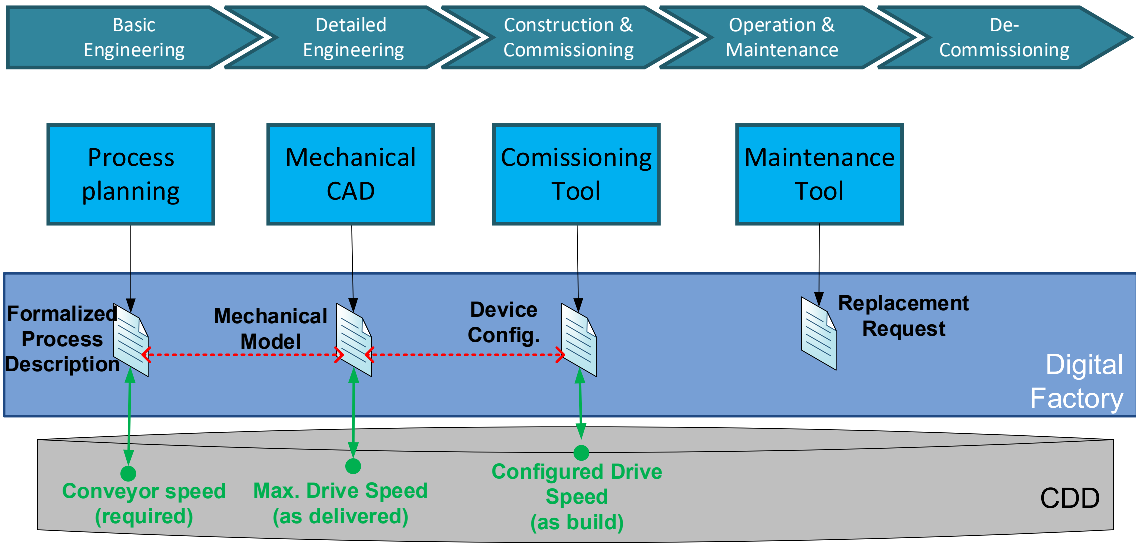

Figure 3 – A common base for systems engineering

IEC 62832: The DF framework specifies model elements and their usage rules for constructing and managing a Digital Factory, a digital representation of a production system, and consists of three parts. The outline of each part is explained below.

3.2 Part 1: IEC 62832-1 General principles

Part 1 defines the basic principles of the DF framework.

The DF framework is a framework for creating and managing a Digital Factory. Defining the DF framework as an international standard facilitates developing interoperable engineering software and tools and enables multiple enterprises to collaboratively use information in a borderless fashion.

Dictionary-based information for the engineering of production systems is classified into 3 categories:

- meta-type information,
- type information and
- instance information.

Meta-type information is provided in data dictionaries as a base for asset descriptions. At this level, the syntactic, semantic, and structural standards are defined for the description of assets. Type information is provided in libraries or in e-catalogues providing information about product types and component types. At the level of instance information, the descriptions of production systems or parts of a production system are provided in Digital Factories.

This part of IEC 62832 defines the general principles of the Digital Factory framework (DF framework), which is a set of model elements (DF reference model) and rules for modelling production systems.

A Digital Factory is a computer-based digital representation of an existing or planned production system. Its information may be shared and utilized among various activities and software programs of enterprises involved in constructing and managing the production system. The contents are added, changed, deleted, and then shared during various engineering activities as the life cycle of the production system progresses. The relationship between a Digital Factory and enterprise activities in the life cycle of production systems is shown in Figure 4.

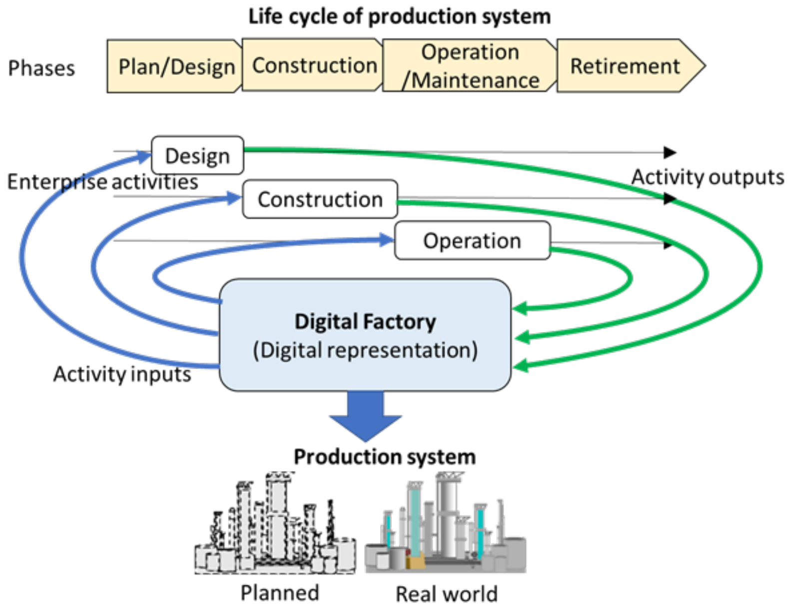

Figure 4 – Relationship between Digital Factory and enterprise activities

A Digital Factory is a collection of DF assets each of which is representing an individual component (PS asset) of a real-world production system. Relationships between the components are represented by DF asset links (Figure 5). A DF asset can represent not only the characteristics of the equipment in the real world but also its role. The represented component of the production system can be a part, device, machinery, and control system.

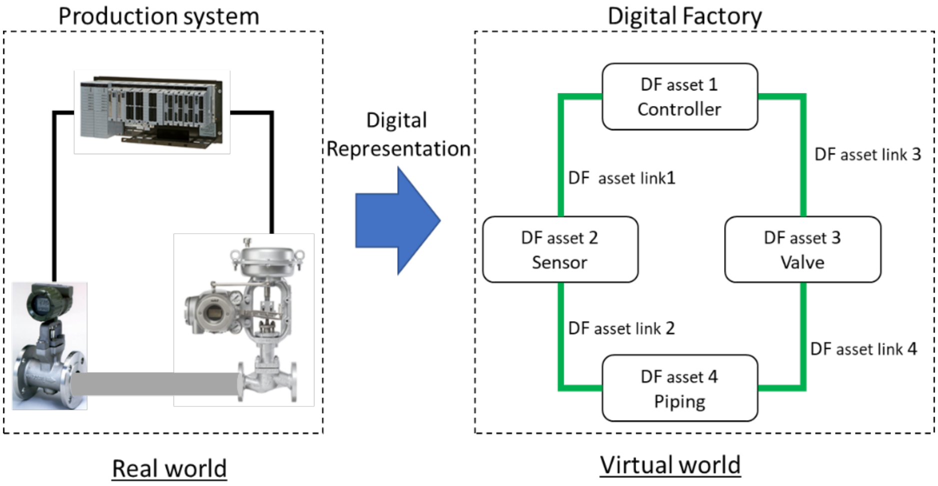

Figure 5 – Simple Digital Factory example

Each DF asset is created based on the information in an electronic catalogue called library provided by the manufacturer of the represented equipment. The contents of the libraries are interpreted by definitions in the data dictionaries which are managed by international standardization organizations or consortia. An enterprise owning the production system creates its own DF dictionary which is a data dictionary that contains necessary definitions, and its own DF library which includes necessary catalogue information, for creating and managing a Digital Factory (Figure 6).

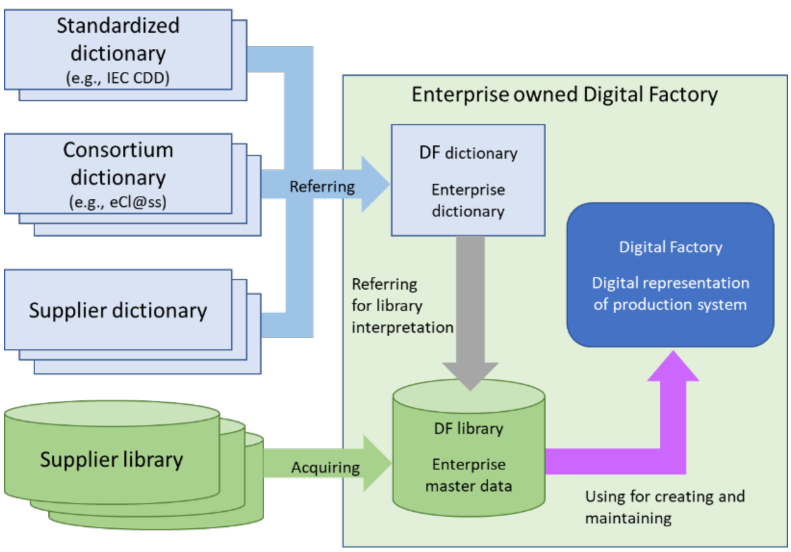

Figure 6 – DF framework structure

3.3 Part 2: IEC 62832-2 Model elements

3.3.1 Overview

Part 2 precisely defines the structure of model elements for representing the Digital Factory, the data dictionaries and the libraries. It also defines the multiple types of data elements that compose those model elements. However, in order to ensure flexibility and expandability of the implementation, no format is specified for the model elements. The main model elements are described as in the following. In order to clearly identify the names of the model elements, the following descriptions use 'PascalCase' for the names (as in Part 2 and Part 3).

3.3.2 Model elements related to Digital Factory

1) DigitalFactory is a model element that represents an entire production system or a part of a production system. A Digital Factory is positioned at the top of the DFasset hierarchy that represents various equipment.
2) DFasset is a digital representation of the individual equipment that makes up the real-world production system and is uniquely identified within a Digital Factory. The DFasset may include multiple DataElements indicating the characteristics and roles of the represented equipment. Also, a DFasset can further include constituent DFassets and DFassetLinks that represent associations between the contained DFassets. This allows a DFasset to have a structural hierarchy from the Digital Factory, which represents the entire production system, down to the atomic parts.
3) DFassetLink is a digital representation of the relationship between real-world equipment and is uniquely identified within a Digital Factory.
4) DataElement is the minimum unit of information used to represent a characteristic of a PS asset or of a role. It provides the corresponding value (DataValue) and includes a reference to a DataElementType (DET) representing its type and semantic information. The DataElement can also have the additional information such as unit of value, time, and quality. In addition, an identifiable group of multiple DataElements, which is called CollectionOfDataElements (CDEL), can be used for specific purposes such as collectively representing the related feature (e.g. interface) of the equipment.

3.3.3 Model elements related to Library

1) Library is a collection of catalogue data (LibraryEntry) such as DFassetClass. A DFassetClass represents the type of equipment used in the production system. The Libraries are classified into Supplier Library and DF library according to their usage.
2) SupplierLibrary is a database used by equipment suppliers to provide equipment users with information related to each equipment type, for instance as catalogue data. It is like an electronic catalogue of each supplier.
3) DFlibrary is a database for the catalogue data necessary for construction and management of a production system collected from multiple equipment suppliers and put together in one place by the enterprise owning the production system. In other words, it is the master data of the equipment type that can be used by the enterprise.
4) LibraryEntry is the individual contents of the Library. Types of LibrarEntry are:
5) - DFassetClass representing the characteristics of each equipment type or role type,
6) - DFassetClassAssociation showing the applicable relationships between DFassets,
7) - DataElementRelationship that specifies the rules for relationships between DataElements so that relationships between DFassets can be evaluated.
8) DFassetClass is equipment catalogue data describing the characteristics of a equipment type. Information such as DataElements included in DFassetClass may be inherited to DFassets.

3.3.4 Model elements related to Data Dictionary

1) ConceptDictionary is a collection of ConceptDictionaryEntries referred to by an identifier called ConceptIdentifier. ConceptDictionaries are classified into standard dictionary, consortium dictionary, or supplier dictionary according to the provider.
2) DFdictionary is a ConceptDictionary dedicated to an enterprise and is set of ConceptDictionaryEntries necessary for interpreting the DFlibrary and the Digital Factory.
3) ConceptDictionaryEntry is a definition of a concept (a term used in DF framework). It contains an identifier (ConceptIdentifier), a common name (PreferredName) and a definition sentence (Description). Each ConceptDictionaryEntry defines its purpose. The following types of ConceptDictionaryEntry are specified: DataElementType; CDELdefinition; and DFassetClassDefinition. These ConceptDictionaryEntries are described in the following.
4) DataElementType is a unit of data that specifies the type, meaning, unit of measure, permissible values, and so on of derived DataElements. DataElementType is referred from DataElement by an identifier (ConceptIdentifier) and provides background for correctly understanding the value (DataValue) and the meaning of the DataElement.
5) CDELdefinition defines a grouping of DataElementTypes for a specific purpose (e.g. for describing a feature of an asset).

6) DFassetClassDefinition defines the general structure of DFassetClass, and multiple DataElementType and CDELdefinition used in DFasset are referenced. DFassetClassDefinition is used as a template when generating DFassetClass.

3.3.5 Definition of individual, specific data element types (DataElementType)

In order to define the model elements as described above, multiple specific data element types (DataElementType) constituting their model elements are defined in Part 2. Particularly important DataElementTypes are explained below.

1) ConceptIdentifier is an identifier for determining an individual ConceptDictionaryEntry included in a data dictionary uniquely in the world. Adopting a unified format for this identifier enables to identify each concept accurately, regardless of language or culture, anywhere in the world. ConceptIdentifier is the core element of the DF framework and also the key to semantic interoperability. DF framework adopts IRDI (international registration data identifier) defined in ISO TS 29002-5 as the format of ConceptIdentifier.
2) Description is a normative text that explains the definition of such as a concept. It is typically provided in English language but it can also be provided in different languages without changing its meaning.
3) PreferredName is a common name given to each concept. Although the concept is accurately identified by ConceptIdentifier, PreferredName is specified for human understanding and reference. It is possible to specify a Preferred Name for each language used, and it is also possible to specify another name (SynonymousName).

3.4 Part 3: IEC 62832-3 Application of Digital Factory

Part 3 defines the rules for using the DF framework for the purpose of representing production systems.

Part 3 specifies the following types of rules for managing the information of a production system throughout its life cycle:

1) Rules for representing the production system by Digital Factory,
2) Rules for representing the real equipment and the roles by DFasset,
3) Rules for representing the relationship between equipment by DFassetLink,
4) Rules for representing the hierarchical structure of equipment,
5) Rules for checking whether the related equipment works properly together (Compatibility), and
6) Rules for deriving model elements from each other.

3.4.1 Relationship between typical model elements

Figure 7 shows typical relationship between model elements at different level of information. A DFasset is derived from a DFassetClass. A DFassetClass is derived from a DFassetClassDefinition. Such derivation is not an inheritance relationship. A DFassetClassDefinition defines all possible features and characteristics that a class of assets might have. A DFassetClass describes, which of these features actually may be present in a product type. A DFasset describes the existing features and properties of the specific PSasset, including application specific features, characteristics, and parameters.

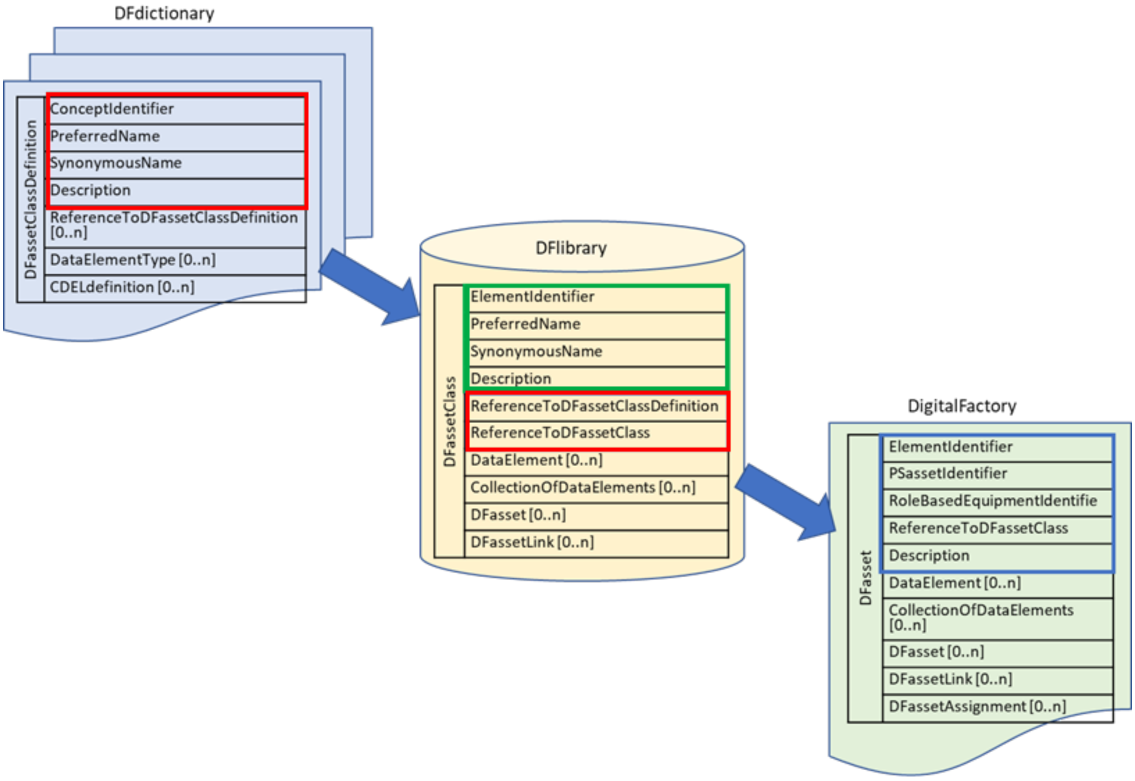

Figure 7 – Relationship between typical model elements

3.4.2 Implementing the DF framework

As explained earlier, the DF framework does not provide its own data format and it is not intended to be implemented as a competition to existing engineering data formats. Instead, the intention is to implement the DF framework through existing data formats and technologies. Each technology is intended to be used in different domains and at different levels of information. This means that these technologies or standards have different strengths and weaknesses at the different levels of information.

The intention of the DF framework is to provide a bridge between standards which are very strong at one level (like IEC 61360 at the meta-type level) and standards which are very good at another level (like AutomationML or CAEX at the type and instance level).

That is why IEC 62832-2 proposes mappings to IEC 61360 and ISO 22745, and IEC 62832-3 proposes mappings to AutomationML and OPC UA. See Table 1.

A similar mapping is being defined for the IEC new work item “Asset administration shell for industrial applications” (see NP 65/761/NP).

Table 1 – Strength of standards at different levels of information

<table>
<tr><th></th><th>IEC 61360</th><th>IEC 61987</th><th>IEC 62832</th><th>IEC 62714 AML</th><th>IEC 62541-100 OPU UA DI</th></tr>
<tr><td rowspan="5">Meta-Type</td><td>++</td><td>++</td><td>++</td><td></td><td></td></tr>
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<tr><td rowspan="5">Instance</td><td></td><td></td><td>++</td><td>++</td><td>++</td></tr>
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Using IEC 62832 as a common reference will allow to derive information at the type and instance level from the definitions at the meta-type level in a common way and will help engineering systems to understand the relation between information provided in different data formats.

This means it is now possible to develop a semantic mapping for information in conventional engineering systems that can later be reused in smart manufacturing systems.

4 Summary

IEC 62832 is an international standard that defines model elements and rules for managing information to establish and maintain a digital representation of production systems. As such it provides a base for digitization of documentation related to production systems, which is applicable for conventional engineering as well as for smart manufacturing.