Development of Industry 4.0 models and their applicability for BIM

Maximilian Both[1,*], *Jochen* Müller[1], and *Björn* Kämper[1]

[1]TH Köln - University of Applied Sciences, Institute of Building Services Engineering, 50679 Cologne, Germany

Abstract. Industry 4.0 (I4.0) and Building Information Modeling (BIM) are representative of the concept of digitisation in different industries. Although both concepts pursue the same goals and apply the same methods, there is no exchange or synchronisation. Investigations of a research project show that I4.0 models are suitable for the description of plant components in building technology and can be integrated into BIM solutions. Weaknesses of BIM in operation can be closed by I4.0 models. The development of I4.0 submodels is a central point of current I4.0 developments. A procedure model has been developed that can be used for deriving and assigning submodels of different assets.

1 Introduction

The digital transformation is in full swing and extends to every area of life. More and more devices are connected to the Internet, resulting in an ever-growing amount of data. By 2025, this should lead to an annual data growth rate of 30 percent [1]. By intelligently linking products and processes, this data can be used to optimise the value chains of manufacturers and users. This leads to novel products and services that offer potential for users to optimise their own business processes. Innovative services are based on information that is created and exchanged during the lifecycle of assets. The term asset stands here for each object, which has a value for an organisation [2]. An asset can be both a physical object such as a pump or an intangible object such as the plan of the building in which the pump is used.

While Building Information Modeling (BIM) is synonymous with the digital transformation of the construction industry, Industry 4.0 (I4.0) stands for the digitisation of industry. The definitions of BIM and I4.0 focus on standardised information that is available throughout the lifecycle [3, 4]. This standardised information has to be made available independent of both manufacturer and platform so that it can be used as a basis for innovative applications [4, 5]. Information that is not standardised but based on manufacturer-specific semantics leads to barriers to the development of the performance of new services.

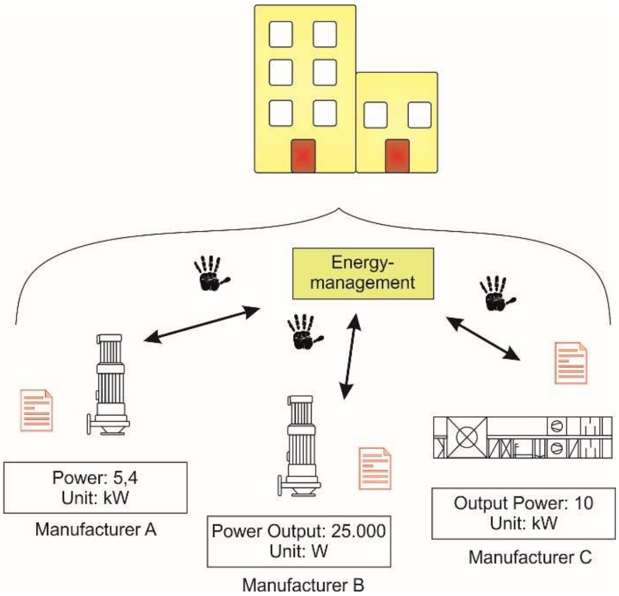

Fig. 1. Different semantics as an obstacle to innovative applications

Figure 1 shows the problem of different semantics. If the information generated by the systems of a building is based on different semantics, this makes it difficult to create innovative applications. The figure shows various components with the property "Power Output". Due to the different semantic characteristics of the performance, it is not possible to automatically record and analyse the performance data of the plants. The manufacturer-specific information requires manual engineering in order to classify the data and make it available to the application. This problem applies to industrial plants as well as to technical building equipment (TBE). Although the concepts BIM and I4.0 pursue the same goals, the same

* Corresponding author: maximilian_alexander.both@th-koeln.de

problems have to be solved, and components such as pumps are used in both areas, no joint efforts can be discerned at present. Further developments are not interlinked, but run in parallel. Possible combinations of BIM and I4.0 have not yet been published. One aim of this research project is to show what a combination of these two concepts would look like and how it could be developed.

The following sections first give a short overview of the two concepts. Building on this, a possibility is presented of how BIM and I4.0 can be combined. In the last section, a procedure model for the development of I4.0 submodels is presented.

2 State of the art

Information models form the basis of I4.0 and BIM. While the I4.0 component, in particular the administration shell, is a central aspect of I4.0, the data exchange for BIM is based on the Industry Foundation Classes (IFC) standard. The following descriptions focus on the standardisation of properties, since this is the current focus of developments in both concepts.

2.1. Standardisation of properties in Building Information Modeling

The IFC model is described in the international standard ISO 16379 and was converted into a German standard in 2017 [6]. It is maintained by the "buildingSMART" organisation and is intended to enable manufacturer-neutral data exchange of digital building data.

Furthermore, "buildingSMART" is responsible for the standardisation of features in the context of BIM and one of the initiators of "openBIM". The aim of "openBIM" is to enable the manufacturer-neutral exchange of building models [7]. The "buildingSMART Data Dictionary" (bSDD), which is based on ISO 12006-3, is provided for this purpose. This ISO standard defines an information model which is used as a basis for the development of dictionaries. Different objects such as subjects, actors or properties are defined, which can be related to each other [8].

Different properties are defined by "buildingSMART". The properties of the components are assigned to the objects with the help of "Property Set Definitions" (Pset). These collections are explained below using a pump as an example. For pumps, the collections "Pump Type Common", "Pump P History" and "Pump Occurrence" are provided [9]. The Type Common collection includes various pump ratings, such as the maximum and minimum temperature of the fluid being pumped or the rated speed. Properties related to pump operation are summarised in the History collection. Examples are the current speed or the pump efficiency averaged over the life cycle. Three further properties are summarised in the last collection "Occurrence", which deals with the basic functions of pumps [9].

In addition to pump-specific properties, each pump inherits properties from higher classes. In particular, some collections are assigned to the "Element" class. A total of seven collections deal with the aspects warranty, manufacturer information, environmental aspects, service life and condition of an object [10]. The properties of these collections can be useful for the design and operation of pumps as they provide important information during the order process. The inheritance hierarchy of the IFC model and the collections in which the properties are summarised are shown in Figure 2 using the Unified Modeling Language (UML).

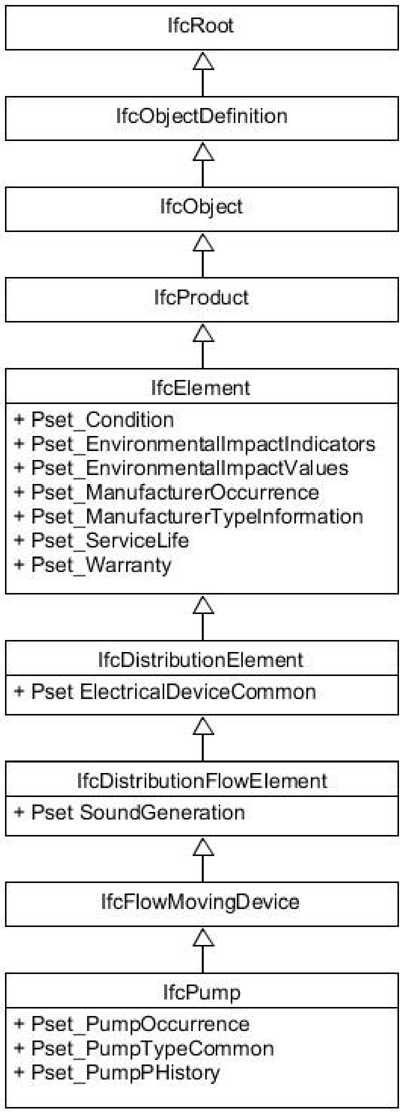

Fig. 2. Possible Pset collections of the pump in connection with the inheritance hierarchy of the IFC model

A total of 93 standardised properties can be assigned to a pump. However, only 16 of these 93 properties are pump-specific [9]. The properties standardised in Pset are all optional. In extreme cases, all 93 properties can be assigned to a pump, or none at all.

2.2 The I4.0 component

The I4.0 component is the core of the I4.0 developments. The I4.0 component consists of an administration shell and an asset. The administration shell represents the I4.0 component in the virtual digital world [11]. The administration shell can be understood as a synonym for the concept of the digital twin. Just like the administration shell, the digital twin is the virtual representation of an asset [12]. Since the term administration shell is preferred in the I4.0 environment, it will be used in the following.

Details regarding the tasks and structure of administration shells are described in various status reports, for example [11, 13]. Among other things, they consist of submodels that describe different aspects of an asset. The development of the submodels and their description by standardised properties with unique identification represents a key task here. In addition to the properties, submodels contain standardised functions, which are summarised as technical functionality [11]. For example, the submodel "operation of heaters" could contain the function "heating".

Current development work deals with the design of administration shells. A working group of the Mechanical Engineering Industry Association (VDMA) and departments "Pumps + Systems" and "Compressors, Compressed Air and Vacuum Technology" is developing submodels for liquid and vacuum pumps. Submodels can be compared with the Pset collections from the IFC model. In both cases, the models, or collections, contain features that describe aspects of an object. Furthermore, there are general models that apply to all components, such as manufacturer information, and models that contain component-specific features [14].

2.3 Industry 4.0 application scenarios in the context of building technology

The working group for "Technology and Application Scenarios" of the "Platform Industry 4.0" examines how digitisation can show new ways and possibilities in the manufacturing industry. Various application scenarios were developed for this purpose [15]. These scenarios were adapted and transferred to the TBE area to show that I4.0 ideas can be transferred to building services engineering. Four of these scenarios and their applicability to building services equipment are described in the following paragraphs.

The first scenario, "Value based services", deals with services that are tailored to needs and uses. This scenario is based on the operating data that is collected and processed. Through an analysis of the data, comparison with target values of planning or manufacturer values, services such as predictive maintenance can be offered. Examples of such recorded data are power consumption of the components or vibration analyses.

Another scenario describes the "Transparency and adaptability of delivered products". The automatic collection of usage-related data from delivered products forms the core of this scenario. Based on this data, status monitoring can be performed and the product properties can be dynamically adjusted in the plant. Furthermore, additional features of the components can be enabled as required. Examples in TBE would be optimisation of the control parameters of individual components to the actual operating conditions, or after-sales services, which are offered to the customer.

In industry, the "Transformable factory" describes a scenario in which production lines are adapted due to short-term changes in production capacities. In TBE, this could be transferred to the replacement of individual components of one manufacturer by those of another. The configuration data is understood by both products so that a manufacturer-independent exchange can be carried out. On the other hand, the idea of "living containers" could be taken up, which could be integrated into different environments through such a "plug and play" scenario.

A fourth scenario, "Continuous and dynamic engineering of plants", describes the engineering of a plant, from the construction and operating phases to disposal. The engineering, operation and service processes interlock and thus extend the original model over its entire life cycle. This principle can be transferred to TBE, since here, too, adjustments are made to plants during operation, which are integrated into the model of the plant or building.

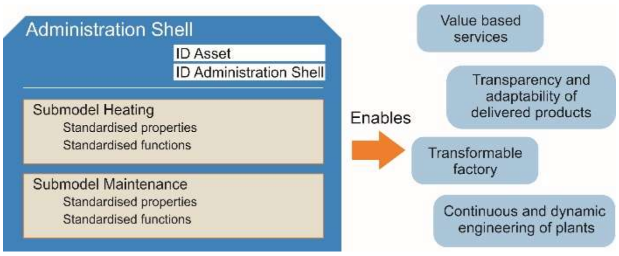

Fig. 3. Administration shell, according to [11], as basis for I4.0 application scenarios

The presented I4.0 scenarios show that these can also be used in TBE. To implement these scenarios, uniform semantic descriptions of the information and standardised functions are required. Without these prerequisites, a high degree of manual engineering would be required to analyse the significance of the information generated. To implement these scenarios, the industry uses the concept of the I4.0 component, shown in Figure 3; in TBE, the BIM method would have to be used. The next section describes whether the concept of BIM is sufficient to cover these scenarios and what a possible combination of I4.0 and BIM might look like.

2.4 Combination of BIM and Industry 4.0

The properties of the "bSDD" for pumps presented in section 2.1 make it clear that the focus of BIM is on planning and the data generated there. Of the 93 possible properties, only six are applicable as current operating data. Accordingly, these data would not be sufficient to cover the operation of plants in their entirety. Discussions that take place around BIM in operation relate to how the models and data generated during planning, for example in Computer Aided Facility Management (CAFM) systems, can be made available. For this purpose, the "openBIM" interface "CAFM-Connect" was developed by various organisations such as "buildingSMART". This is based on the IFC model and provides the planning data in CAFM systems [16]. However, the actual operating data of the plants are essential, especially in TBE. Just as in planning, clear and standardised semantic information is required here in order to be able to automatically evaluate it. In addition, standardised functions are required in order to be able to implement the scenarios from section 2.3. The semantic description of the operational data, however, is currently not the focus of BIM, nor is the development of functions. Therefore, a different concept would have to be used during operation. Therefre, scenarios presented here cannot be implemented with the BIM method alone, since current operating data is required for this.

In contrast to BIM, I4.0 focuses not only on planning but also on operating plants [17]. This becomes clear, for example, in the development of submodels for pumps. In addition to a model for the technical data of the manufacturer and planning, models are developed that describe data from operation and maintenance [14]. These models can close the gap that arises during operation with BIM.

A building in operation is a composition of different assets. All installed objects in the building such as doors, windows, ventilation ducts or pumps can be regarded as assets. Each building has an administration shell (Digital Twin), which in turn is composed of the individual administration shells of the assets. A basic part of the shell is the plan of the building in which the planning data is stored. Further data is added during operation. The presented application scenarios can be implemented on the basis of the manufacturer's, planning and operating data. However, the scenarios can only function automatically if the semantic description of the properties from operation and planning match. If I4.0 models are used in operation, a possibility of combining BIM and I4.0 must be developed. One possibile combination is to use the semantics of the I4.0 models also in planning. This means that the BIM method is still used for the planning of buildings, but the semantic description of the planning and manufacturer data follows the description from I4.0 models. This scenario is shown in Figure 4 below.

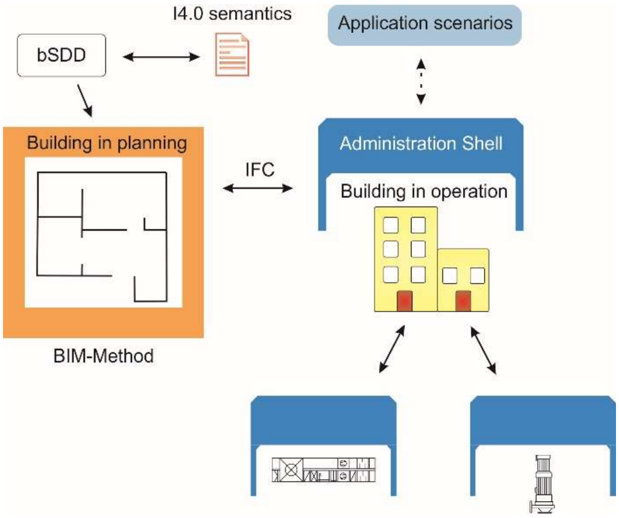

Fig. 4. Combination of BIM and Industry 4.0

One possibility to integrate the semantics of I4.0 into BIM is given by the "bSDD". The "bSDD" is to enable an open exchange of building data. The ISO 12006-3 standard on which the "bSDD" is based enables reference to other classification systems [8]. One example of such integration is the cooperation between "ETIM e.V." and the "buildingSMART" organisation. Since 2017 it has been possible to reference the "ETIM" data model from the "bSDD" [18]. The same mechanism would make it possible to reference relevant I4.0 submodels and integrate their semantics into BIM models. Administration shells used in TBE during operation contain an IFC interface that makes it possible to make the planning data available during operation. This would ensure uniform semantics from planning through operation to the demolition of a building.

The integration of I4.0 submodels in BIM can help to make necessary information about the life cycle of assets available in TBE during operation. A combination of the two concepts would eliminate the need for multiple descriptions and modelling of properties and functions. Plant components would not have to have a BIM conformal description for the planning, as well as an I4.0 conformal description.

The aim is to make the relevant I4.0 submodels of planning available in the "bSDD" or to reference them. The presented method can be used for this. However, the development of I4.0 submodels is currently still in its infancy. As of today, no official submodels have yet been adopted.

3 Proposal for a process model

A prerequisite for a combination of I4.0 and BIM is the development of submodels for components of TBE. A VDMA working group is currently working on submodels for liquid and vacuum pumps. The aim of the working group is the standardisation of an administration shell for pumps. The submodels for liquid pumps will also be used in TBE. Examples of submodels have been presented in various reports [13]. However, there is no model that describes how to proceed with the development of submodels. Figure 1 shows the problems of different semantics. However, this problem can also be extended to submodels. Different terms, like the "performance" shown in the figure, are relevant for different components. Properties that are important for several assets should be defined only once, if possible, and used in the respective submodels of the assets. The VDMA Working Group for Pumps has developed a procedure model that can be used for the derivation and assignment of submodels. The described procedure should be applicable to different assets. The proposal is based on a process and life cycle oriented modelling of asset functions. Furthermore, a classification is suggested, with which assets can be summarised in groups and structured hierarchically. With the help of the procedure model, the development of submodels can be simplified. More manufacturer associations of TBE such as the VDMA professional associations "Refrigeration and Heat Pump Technology" and "Air Conditioning and Ventilation Technology", should be encouraged to develop I4.0 submodels.

3.1 Life cycle phases as the basis for submodels

The first part of the proposal is used to derive submodels. The phases of the life cycle that every asset goes through serve as a basis. In order to achieve a generally valid approach, international standards are used. Starting point for the structuring of the submodels in the life cycle is the reference architecture model 4.0 (RAMI 4.0).

RAMI 4.0 was developed to combine different aspects of I4.0 in one model [19]. A three-dimensional model was designed for this purpose. Since the procedure model is oriented to the life cycle of assets, only the axis of the life cycle is presented. In RAMI 4.0, the life cycle was based on IEC 62890 [20]. The basis of this standard is the distinction between the type and the instance of an asset. The "type phase" extends from the initial idea of a product to the release of series production. The "instance phase" extends from the production of the instance, based on the general type, through its use, to the disposal of the product [21].

Based on this general distinction between type and instance, the process model describes the life cycle of an asset on the basis of basic processes. ISO 15288 was used as the basis for life cycle processes. This standard provides defined processes that describe the life cycles of technical systems [22]. The processes provided in the standard were analysed to determine whether they can be used as a basis for the submodels. The processes that can be used as a basis were included in the model and assigned to the two life cycle phases of RAMI 4.0. Regardless of the procedure model, various use cases were created at the beginning of the working group. This made it possible to define the priorities of the members with regard to the development of the submodels. The different use cases were compiled and examined for overlaps and combined into superordinate use cases. In a next step, these use cases were located in the life cycle model and assigned to the processes.

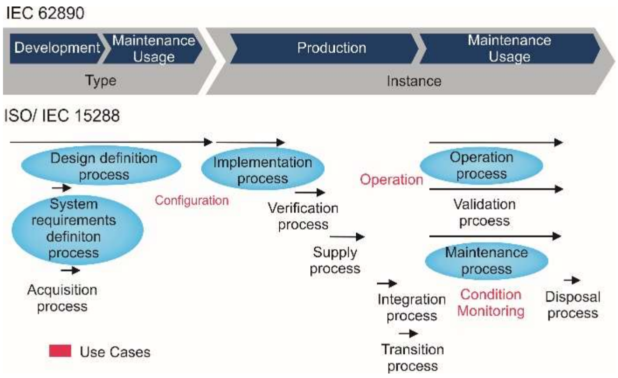

Fig. 5. Assignment of life cycle processes to the RAMI 4.0 life cycle model and location of use cases

The upper part of Figure 5 shows the basic subdivision of the life cycle of a product into the type and instance phase according to IEC 62890. The processes are shown below. These were classified along the life cycle. In addition, the manufacturers' use cases were assigned to the processes. The use case "Configuration" is split to the three processes "Design definition process", "System requirements definition process" and "Implementation process". As a result of this use case, a preconfigured pump is to be delivered that meets the customer's requirements. For example, the correct working points can be set in advance. The use cases "Operation" and "Maintenance" correspond to the two processes "Operation process" and "Maintenance process".

The basic processes form the basis of the submodels. The functions presented are general in nature so that they can be applied to any asset. On the basis of these functions, more specific functions can be modelled that fulfil the characteristic requirements of an asset or an industry. Figure 6 uses UML to illustrate how submodels can be derived from the basic processes "Operation" and "Maintenance".

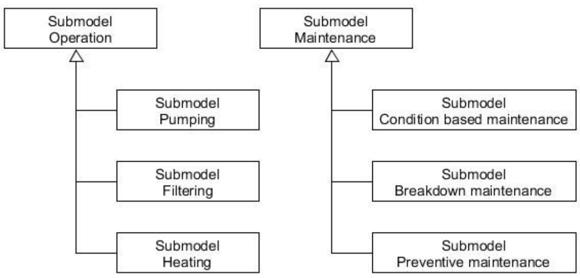

Fig. 6. Submodels derived from general processes

Examples for specific functions of TBE components in the "Operation Process" are the functions "pumping" of the pump, "filtering" of the filter or "heating" of the heater of a ventilation system. For maintenance submodels, DIN

EN 13306 can be used as the basis in which basic terms of maintenance are defined [23].

3.2 Classification of Assets

The second part of the procedure model deals with the classification of assets. The goal is to standardise properties that describe the same thing only once, if possible. This is to prevent properties that are valid for several assets from being defined more than once. A classification is needed to group assets and receive a hierarchical structure as to which assets can be summarised in same groups. The "International Standard Industrial Classification of All Economic Activities" (ISIC), which is used for the classification of economic sectors and branches of industry [24], is suitable for this purpose. The hierarchy of the standard is shown in excerpts in Figure 7, with a focus on the TBE.

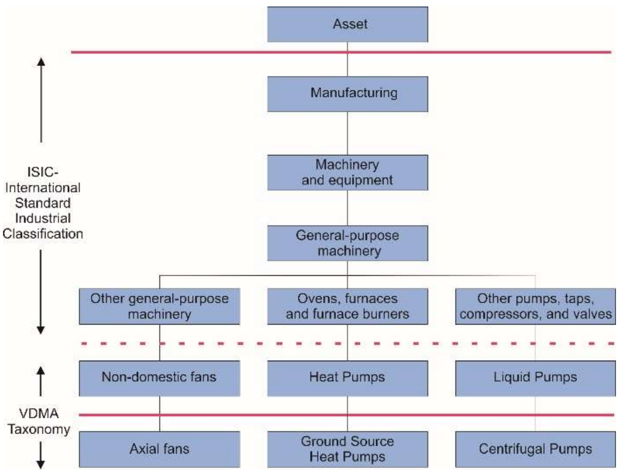

Fig. 7. Classification of Assets

The ISIC classification has been extended upwards and downwards (represented by the red lines). The general class "Asset" was introduced above the main groups. Further classes were introduced below the last subcategory in order to be able to define the hierarchy of the assets more precisely. The main group shown is "manufacturing industry", which is one of the 21 main groups provided by ISIC and is in turn divided into 24 subcategories. These include, for example, the manufacture of textiles, paper and electrical components [24]. A further subcategory is "mechanical engineering", which is included in the figure. Starting from the category "Mechanical engineering", further categories are defined such as the subcategory "Non-industry-specific machinery". The last stage of the ISIC introduces further subcategories. The areas "Pumps, compressors, taps and valves", "Furnaces and burners", as well as "Other non-tool-specific machines" have been included in the figure, as components of TBE are located here. The figure shows that all assets can be mapped with the help of the standard. In the lowest categories of the ISIC, the basic contents of these categories are described, but no further grouping is introduced.

However, these contents described here are not sufficient for guaranteeing an exact classification of the assets. The categories must be further subdivided for this. Figure 8 shows a further subdivision using a pump as an example.

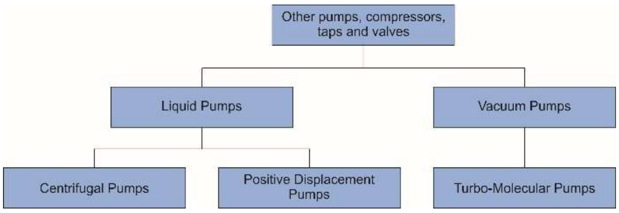

Fig. 8. Finer structuring using a pump as an example

The professional associations of the VDMA distinguish between the two pump types "vacuum pumps" and "liquid pumps". For this reason, this distinction was also taken into account in the development of the submodels. Furthermore, liquid pumps are distinguished between "centrifugal" and "positive displacement" pumps. The "turbomolecular pump" is shown as an example of a vacuum pump. In the further subdivision, the VDMA taxonomy was used. The further subdivision of the individual categories should also be carried out in other areas by the working groups, which want to develop submodels for a certain domain. Here also other taxonomies can be used.

3.3 Combination of basic processes and classification of assets

The following section combines the two parts of the procedure model: the combination of the basic processes and the classification results in the basis for the reusability of properties. This is illustrated in Figure 9.

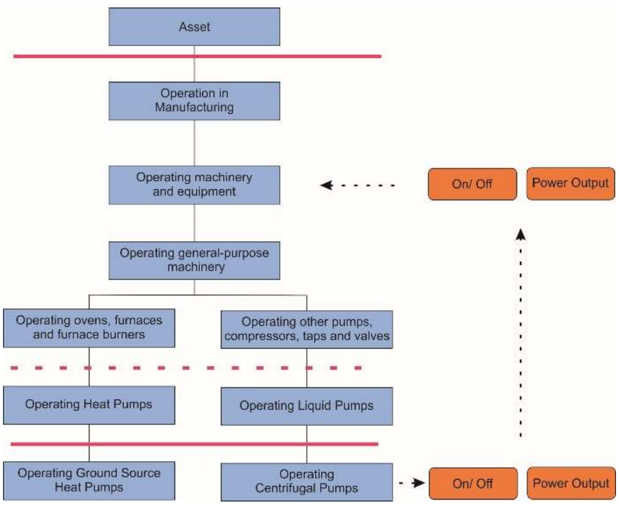

Fig. 9. Reusability of parameters

The submodels for operation are derived from the "Operation" process. At the lowest level, the submodels "Operating ground source heat pumps" and "Operating centrifugal pumps" are derived. When defining the properties, the "bottom-up" principle should be applied. The working group defined the properties for the different pump types (centrifugal pumps, positive displacement pumps, various vacuum pumps). The properties that are valid for all liquid pumps or vacuum pumps were analysed. The next step is to define which of the properties can be used for both liquid and vacuum pumps. With this point, the internal work of the working group is finished, since it was defined, which properties are assigned to the different categories. In a next step, the working group has to define which properties are valid for "Non-industry-specific machines".

The function "On/Off" and the property "Power" are included in the figure. "However, "On/Off" and "Power" are not pump-specific functions or properties, but are valid for all assets that can be switched on and have a drive. These two properties are therefore good examples of features and functions that can be assigned to a higher level of classification and are therefore valid for multiple assets.

3.4 Standardised properties as a basis for interoperability

The model presented should provide guidance on how to proceed with the definition of submodels. The derivation of the submodels of basic processes and the classification enable a uniform structure of the models and reusability of the parameters. The problem of manufacturer-internal standards was described in figure 1. This problem can be solved by uniform submodels and standardised properties. This is represented in figure 10.

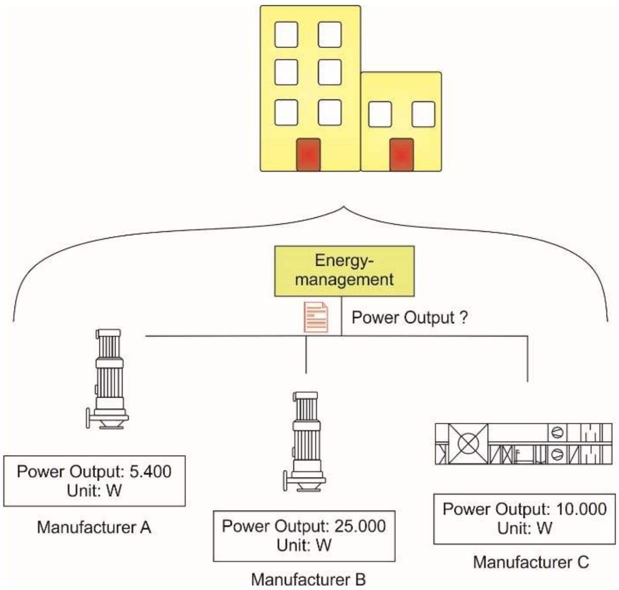

Fig. 10. Uniform standards as a basis for interoperability

The two pumps shown, from two different manufacturers, are based on the same submodels. The uniform structure of the pumps makes it easier for energy management applications to access the pump data. Since performance is not only valid for pumps, it has been assigned to a higher level in the classification and is also valid for other components. This allows the performance property not only to be the same for all pumps, but also to be used by other components of this characteristic. This allows applications to query the performance data of components and use it for analysis purposes without a great deal of manual engineering.

4 Conclusion

BIM and I4.0 stand for digital transformation in different industries. The definitions and developments in the last few years show that both pursue the same goals. With manufacturer-independent standards, an unrestricted exchange of the information can be made possible over the entire life cycle of an asset. Essential for this are open standards, which define the semantics, with which the properties of the assets are described. Although both concepts pursue the same goals and the same methods are applied, digitisation activities currently run separately in both concepts. The current focus of BIM is on building design. There is no concept on how to capture operational data. This gap can be closed by I4.0 submodels, since these cover the operation. In order to achieve uniform semantics over the entire life cycle and thus avoid information breaks, I4.0 submodels must be integrated into the BIM method. This integration is provided by the "bSDD", since this allows the reference to external classifications. Thus, the semantics of the submodels can be integrated into BIM models, enabling uniform and consistent availability of the information over the entire life cycle.

However, the development of I4.0 submodels is still in its infancy. A VDMA working group is currently developing I4.0 submodels for liquid and vacuum pumps. In the course of the group's work, a proposal for a procedure model for the creation of submodels was developed. The aim is to create a uniform basis for the derivation of submodels and to prevent the multiple definition of properties that apply to several assets. The proposal consists of two aspects. On the one hand, basic asset functions were modelled on the basis of a life cycle model, which forms the basis for the submodels. The functions are of a general nature, so that models can be developed for each asset on the basis of these functions. On the other hand, a classification was presented in which each asset can be located. The classification is based on the international standard "ISIC". However, the standard is extended downwards by further categories, which allows a finer division of the assets. With the help of this model, submodels can be derived and the assets classified.

References

1. Data Age 2025: The Evolution of Data to Life-Critical. Don`t Focus on Big Data, Focus on Data That`s Big, International Data Corporation, Framingham, USA (2017)
2. Fraunhofer IOSB: Begriffsdefinition rund um Industrie 4.0. Glossar des VDI/ VDE GMA Fachausschuss 7.21 "Industrie 4.02. http://i40.iosb.fraunhofer.de/Asset, abgerufen am: 16.08.2018
3. Stufenplan Digitales Planen und Bauen. Einführung moderner, IT-gestützter Prozesse und Technologien bei Planung, Bau und Betrieb von Bauwerken, Bundesministerium für Verkehr und digitale Infrastruktur, (2015)
4. Umsetzungsstrategie Industrie 4.0. Ergebnisbericht der Plattform Industrie 4.0, BITKOM e.V., VDMA e.V., ZVEI e.V., (2015)
5. Umsetzung des Stufenplans Digitales Planen und Bauen. Erster Fortschrittsbericht, Bundesministerium für Verkehr und digitale Infrastruktur, (2017)
6. DIN EN ISO 16739; 2017. Industry Foundation Classes (IFC) für den Datenaustausch in der Bauindustrie und im Anlagenmanagement
7. Entwurf VDI 2552 Blatt 2; 2018. Building Information Modeling
8. DIN EN ISO 12006-3; 2017. Bauwesen – Organisation von Daten zu Bauwerken
9. building SMART Data Dictionary. http://bsdd.buildingsmart.org/#concept/details/1xPUW0qVuHuO00025QrE$V, abgerufen am: 06.08.2018
10. building SMART Data Dictionary. http://bsdd.buildingsmart.org/#concept/details/00ZjG0qU8HuO00025QrE$V, abgerufen am: 06.08.2018
11. Struktur der Verwaltungsschale. Fortentwicklung des Referenzmodells für die Industrie 4.0 Komponente, Bundesministerium für Wirtschaft und Energie, (2016)
12. Fraunhofer IOSB: Begriffsdefinition rund um Industrie 4.0. Glossar des VDI/ VDE GMA Fachausschuss 7.21 "Industrie 4.02. http://i40.iosb.fraunhofer.de/Digitaler%20Zwilling, abgerufen am: 16.08.2018
13. Beispiele zur Verwaltungsschale der Industrie 4.0-Komponente- Basisteil. Fortentwicklung des Referenzmodells für die Industrie 4.0 Komponete, ZVEI e.V., (2016)
14. Both, M. u. Müller, J.: Entwicklung einer Industrie 4.0 Verwaltungsschale auf Basis des allgemeinen Geräteprofils für Pumpen. In: Automation 2018
15. Fortschreibung der Anwendungsszenarien der Plattform Industrie 4.0. Ergebnispapier der Plattform Industrie 4.0, Bundesministerium für Wirtschaft und Energie, Berlin (2016)
16. CAFM RING: CAFM-Connect. https://www.cafm-connect.org/, abgerufen am: 16.08.2018
17. Döbrich, U., Heidel, R., Hoffmeister, M. u. Hankel, M.: Industrie 4.0. Basiswissen RAMI 4.0: Referenzarchitekturmodell mit Industrie 4.0 Komponente. DIN e.V. 2017
18. ETIM Deutschland e.V.: Pressemitteilung Kooperation ETIM international- buildingsmart. ETIM international und Buildingsmart international unterzeichnen Kooperationsvertrag. (2017)
19. Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0), VDI/ VDE e.V. u. ZVEI e.V., (2015)
20. DIN SPEC 91345; 2016. Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)
21. Norm-Entwurf DIN EN 62890; 2017. Life-cycle-Management von Systemen und Produkten der Mess-, Steuer- und Regelungstechnik der Industrie
22. ISO/ IEC/ IEEE 15288; 2015. Systems and software engineering- System life cycle processes
23. DIN EN 13306; 2018. Instandhaltung
24. International Standard Industrial Classification of All Economic Activities (ISIC), Rev.4, Department of Economic and Social Affairs, Statistic Division, (2008)