Using Existing Standards as a Foundation for Information Related to Factory Layout Design

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Abstract
In the current factory layout design domain, the factory layout is usually a geometric representation. The domain suffers from many problems such as inadequate types of geometrical information, difficulties in combining different file formats and comprehensive information management. This paper describes the problems, needs and visions in the domain. The authors have identified several existing standards that are suitable as a foundation for information related to factory layout design, for a more integrated information management and for efficiently creating and analysing factory solutions. A detailed description and discussion about diverse standards are included in the paper.

Keywords:
Factory layout design, Standards, Information representation

1 INTRODUCTION

Many manufactures today are constantly changing and developing their factories, manufacturing systems or buildings due to different needs and challenges. The reasons can be the need to manufacture a new product, expansion, demand for shorter throughput time, etc. All of these are drivers for a better factory planning and factory layout design. This study focuses on how to represent factory layout design related information using existing information standards that are not delimited to factory layout information representation. Today there are no information standards dedicated only for factory layout design, but there are some other information standards which are partially suited for factory layout design in different ways. This study focuses only on machining and assembly factories.

2 DIFFERENT TYPES OF FACTORY LAYOUTS

Factory layout is considered to be at the core of the factory design process. During the development of the factory planning pilot in the ModArt project, it was identified that the layout development is the most essential activity in factory design [1]. During factory layout, different domain models of media, machines and building etc. are merged together. It is in the factory layout where the results of the product flow simulation will appear in relation to the equipment. A good virtual layout is a layout that can be utilised for verification of realisable combination of objects from different domains. For example, it will determine if the foundation and a machine-tool fit together in size and weight. A detailed factory layout specifies a part of the flow and has an effect on the factory during its life time, in terms of shorter throughput time, better space utilisation and more. This means that while developing and realising the layout for a factory, information about machine weight, foundation load capacity, electrical port location, etc. is important. It should be possible to represent this information in the factory layout model for the efficient creation and analysis of factory solutions. This, in turn, means that a good layout is not just a graphical representation, it is the model for all required information. Fulfilment to standards and laws related to e.g. safety can also be verified in the factory layout model.

Factory layout model is a very wide concept and has different meanings. As for all kinds of models, the factory layout model has purposes, viewpoints and detailed levels for its information. It is further explained in section 4. Below are some of the views that a factory layout can have in the factory design domain. These views on layouts need to be considered in the information standard evaluation.

- Block layout:
  The block layout is a layout used in an early stage of the layout design process. In 2D drawings or 3D models, machines are just represented conceptually by boxes with approximated size or just a marked sub-area, meaning that much of the information about the machines doesn’t have to be specified. The most important part in the block layout is the division of the space, e.g. the area of machines, buffers, operator space and maintenance areas [2].
- Detailed layout:
  A detailed layout [2] should contain all the information needed to describe a system. A system can be a factory, a line, a cell, etc. The information in a detailed layout should be realisable and reflect a real factory at a certain level of detail.
- Media layout:
  A media layout is a generic term for the layout of electric power, process fluids, ventilation, water systems, IT/telephone, and more.

- Foundation layout:

  Many machines or larger pieces of equipment require their own “islands” to stand on due to weight and need to be isolated from disturbances such as vibrations from other equipment. Therefore it is necessary to build a specific foundation for each of them to meet their requirements. A foundation layout describes these specific foundations in terms of dimension, load capacity, material, and more.

Apart from the different layouts above, there are layouts such as working area layout, painting area layout, safety layout, lighting layout, building layout, and more. In the detailed factory layout, many of these layout types need to be merged together for a better verification of available space.

There are three main domains in factory layout: the manufacturing system domain, the media domain and the building domain. As a factory designer, it is important to have the ability to combine these domains.

Figure 1 is an example of an integrated geometrical factory layout of the three domains. Current work methods for integration involve converting different file formats to system acceptable formats, and re-modelling e.g., the geometry for a proper level of detailing. It means that the original layouts in Figure 1 have different file formats and different levels of detail for the geometrical information, and that they have been modified to fit into one geometrical model. Many hours of work and competence in various systems are required to integrate a factory layout with the manufacturing system, media systems and the building. But still it is not sufficient to efficiently develop and realise a factory.

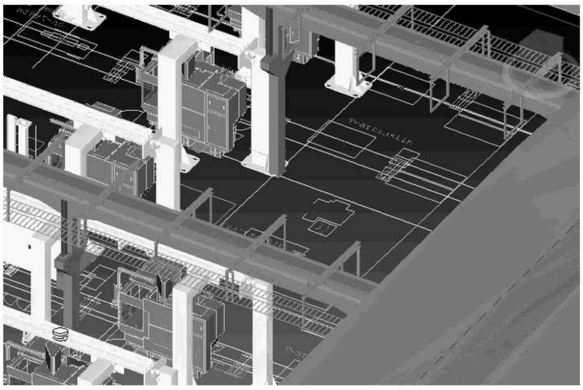

Figure 1: Part of an integrated geometrical factory layout

3 GENERAL PROBLEMS, NEEDS AND VISIONS

There are several identified problems and needs for factory layout:

1. Different file formats make the file exchange problematic. It is difficult to integrate layouts from different domains. For example, in many factory layouts today the media part is usually represented in symbols on separate sheets instead of in the models. It is necessary to have media represented in factory layout models so that e.g., collision can be detected in time.
2. The file sizes of the layouts are usually large, which makes it difficult to combine several layouts for visualising the whole factory system. This problem is often related to geometrical information within each layout file or model. Currently a model contains a lot of geometrical information that is not relevant to factory designers. One typical example is geometrical models of machine-tools from machine suppliers. They usually have too detailed geometrical information about the inner parts of the machines, e.g., spindles. For factory designers the machine outer contour is the most important geometrical information together with some other information such as the openings, footprint and media interface positions. This means that the file size will decrease dramatically if we only sort out the geometrical information relevant for factory designers.
3. Besides the geometrical information, there are other types of (non-geometrical) information to be considered. For example, a machine-tool model contains the type of machine (its functions) as milling or turning, the machine-tool weight (a property), etc. Today this information usually is stored in different repositories and/or data formats such as Microsoft Word, Microsoft Excel or PDF. The information management will be easier if the object properties are stored in an organised structure related to geometry. In this way, the time spent on finding usable information will decrease and information accuracy will increase.

4 LAYOUT DRAWING VS LAYOUT MODEL

It is essential to distinguish the drawing from the model. A layout drawing is often a layout that is a 2D view. A layout model contains much more information compared to a drawing. A layout model should have multiple views :a 3D view or specific view and detailing levels for conveyers, trucks, paths, media, etc. It can support different asynchronous or synchronous collaborations between people/projects. In a layout model, information should be stored for reuse, manipulation and consolidation. In a layout model, the geometrical information should be integrated with non-geometrical information i.e., a combined model (section 3, problem 3), and layout from various disciplines can be integrated i.e., an integrated model (section 3, problem 1). Therefore the factory layout model requires a suitable information model in the future to solve these problems and support the needs and vision from section 3. Currently the integrated factory layout model normally only contains 3D geometrical information.

If a combined model for e.g., a machine-tool exists, further possibilities and advantages may be found by sharing this model between disciplines or reusing this model in other–software applications such as kinematics simulations, operation planning or manufacturing concept planning. The information that is needed to generate behaviours of the system in the factory can be stored in this model. Combining this information with a process will give operation time for the flow simulation or machine-tool power for the power consumption calculation.

To meet the needs above, a standardised information model for information related to factory layout design is essential. This will decrease the file format exchange problem and will improve information management in the factory design area. A standardised information model will also give companies a chance to own their information instead of having the information embedded in commercial system structures which they have no control of. At this stage there is no information standard developed specifically for factory layout design, but there are several which can be used for information related to the factory layout domain.

Here is a summation of reasons to use standards for information related factory layout design:

- For integrated information management among different domains of factory layout design, sharing data is very important. Using the information standards for better knowledge and information management has been suggested in research project including SPECIES [3] and also in a state of art study [4].
- For improved interoperability between software programs.
- For improved availability of information.

A comprehensive assessment has been performed on information collection and evaluation. Information and knowledge about factory layout design and its process were collected, analysed and modelled in a web-based system called “production pilot” [5]. Based on this information and knowledge, the evaluation of existing standards was performed. Generally there are two parts of the evaluation: 1) study of the overall functionality and feasibility of the standard to represent general information related to factory layouts such as geometry, elements within a building, coordinate systems, etc. 2) detailed evaluation mostly based on the three typical issues described below.

5 ISSUES REGARDING FACTORY LAYOUT REPRESENTATION

Apart from the general problems and needs, there are some typical issues related to information representation in factory layout design e.g.:

1. How to describe (model) the relationship between a machine centre and its electrical cabinet with its cable? This issue includes these main descriptions: geometry of port, connector, electrical cabinet, machine centre and cable, the relationships between objects geometries, the object functions, relationship between functions, and object property e.g., voltage and the location. This issue concerns the manufacturing system domain and media domain.
2. How to describe the relationship between machine footprint and the foundation that the machine is standing on? This issue includes these main descriptions: geometry of machine-foot and foundation, definition of machine foot-print, machine weight, load capacity of foundation, relationship between machine weight and load capacity, foundations material and the location. This issue concerns the manufacturing system domain and building domain.
3. How to describe the relationship between a robot and the machine-opening when there is no the physical contact? This issue includes these main descriptions: geometry of the machine-opening and robot, the envelope of the robot arm and opening, and the function and the relationship between the opening and the arm. This issue concerns the amount of space or distance that is needed between two objects.

These three issues above contain many specific detailed descriptions and there are many similar issues related to them. If these three issues could be represented by standards, the rest of the similar issues can be solved. A small part of the objects, properties and relationships in the issues are listed in Table 1 to exemplify the detailed evaluation.

The detailed shapes of manufacturing systems and resources are not considered in the first stage of the information model evaluations for layout. The CAD part is not the problem because it is a generic part that many domains are sharing, and it is the most developed part in the standardised data exchange world. Product management data (e.g., version, variant and status) is also an essential part of factory design, but this part is not the main focus either, because the evaluation scope will be too broad.

The evaluation of a standard mostly focuses on the questions:

1. Can it represent the objects and their properties within the factory layout design?
2. Can it represent the relationship between manufacturing resources, media resources and building resources to support development and realisation of the factory layout?

6 REFERENCE INFORMATION ABOUT STANDARDS

Three standards have been studied and evaluated in this work: ISO 10303-214, ISO 10303-225 and Industry Foundation Classes (IFC).

6.1 IFC

IFC is registered by ISO as ISO/PAS 16739 and is currently in the process of becoming an official International Standard ISO/IS 16739 [6]. IFC is developed to represent an information model structure for sharing construction and facility management data across various applications used in the building domain [7]. IFC uses the EXPRESS (ISO 10303-11) modelling language for the data schema specification. As the EXPRESS is used, an implementation can be done utilising part 22 SDAI (Standard Data Access Interface) and Part 21/28 files.

6.2 STEP

ISO 10303, industrial automation systems and integration - product data representation and exchange, named STEP (STandard for the Exchange of Product data), is developed to represent the product data model [8]. The objective of STEP is to provide a neutral mechanism capable of describing product data throughout the life cycle of a product, independent of any particular system [9]. Within STEP there are many application protocols (APs) focusing on different areas. In this paper two APs are evaluated: AP 214 and AP 225. For all APs there are two types of models: an application reference model (ARM) and an application interpreted model (AIM). The ARM is the application specific information model and the AIM is an interpretation of the common generic information model provided within STEP. This means that AIM is the conceptual link between different APs

AP 214: Core data for automotive mechanical design processes

AP 214 is developed to exchange information between various software applications within the automotive development process [10]. AP 214 is not specifically developed to represent information related to factory layouts design, but some of the conformance classes are also suited to represent a manufacturing system, seen from the viewpoint of a factory designer. It has also been shown that the AP 214 can represent the basic information for the manufacturing system development [11]. According to M., Johansson [12], AP 214 can also represent manufacturing facilities with certain functionality such as machine shop, paint shop etc. in conceptual design.

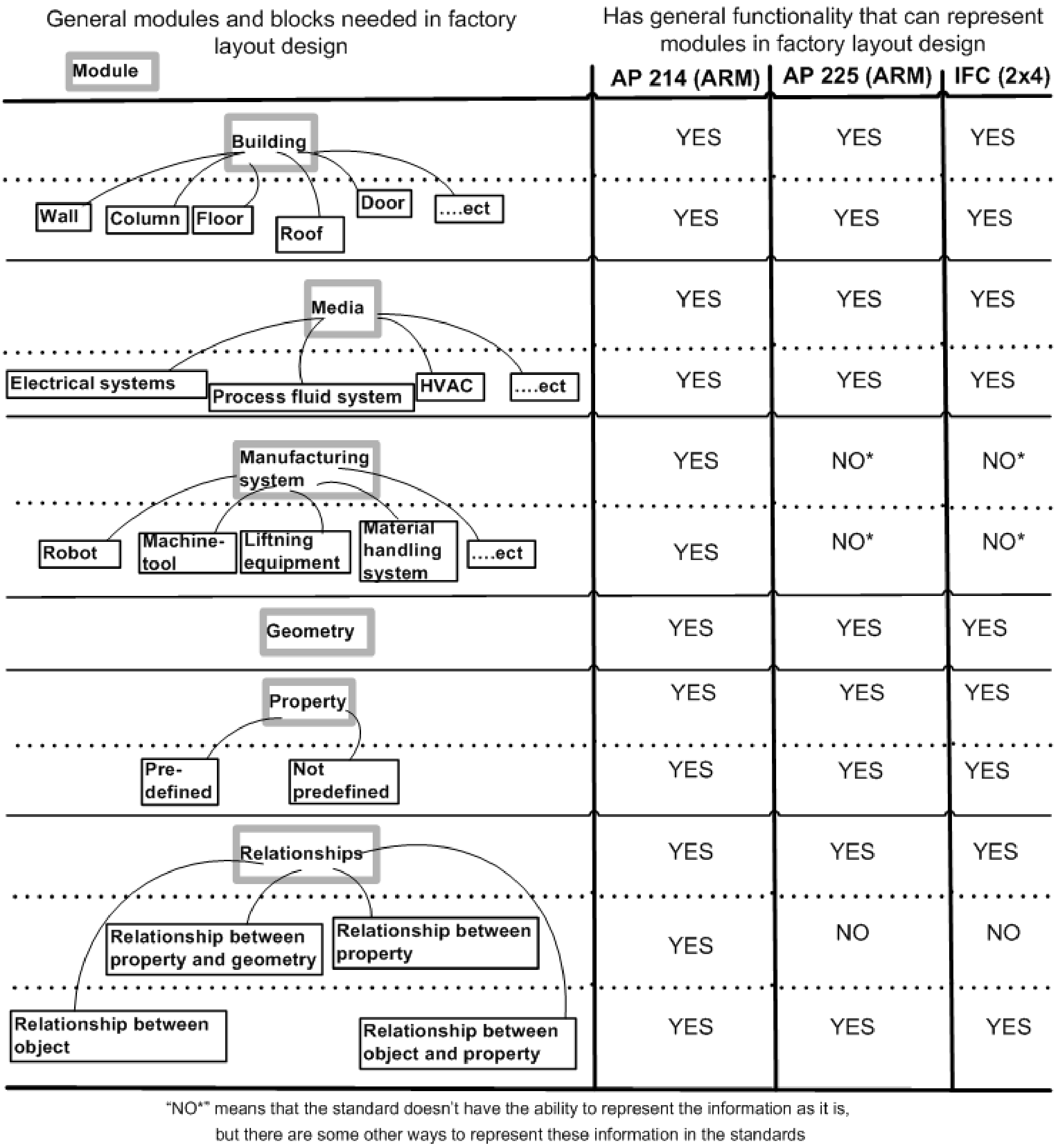

Figure 2: A summation of general evaluation of standards

AP 225: Building elements using explicit shape representation

AP 225 is developed "for the exchange of building element shape, property, and spatial configuration information between architecture, engineering, and construction" [13]. The information within the information model can be used in all stages of the life cycle of the building, from the designing stage to maintenance. The purpose is to assist the exchange of information between software applications in the building and construction sectors. AP 225 can e.g. integrate building structure design with service system design which is a must in the factory design process

7 REPRESENTATION OPTIONS FOR FACTORY LAYOUT INFORMATION

Four different options (see subsections below) are identified regarding how to use existing standards to represent factory layout models based on the evaluation.

Figure 2 shows a result (summation) of the general evaluation. In the figure, "YES" means that the specific information standard has the ability to represent the modules and their information content while "NO" means that it doesn't have the ability to represent the information. "NO*" means that the standard doesn't have the ability to represent the information as it is, but there are some other ways to represent these information in the standards. One example is entity "IfcDistributionElement" from IFC standard originally defined for all elements that participate in a distribution system within a building such as heating system and ventilation system. But this entity can be used for the machine-tool representation. Figure 3 is a simplified instantiation of IFC with main entity "IfcDistributionElement" representing a machine-tool with its shape, location, self-defined properties (current and voltage) and relations to other objects.

Further detailed evaluation based on specific issues is required to verify if the specific information can be represented by the standards. It is not sufficient to use a general evaluation to exam the detailed feasibility of standards. The information models and regulations within standards have to be tested with specific information/data to make sure that the standards meet the needs within factory layout design. The detailed evaluation of the standards mostly focuses on the three issues and a part of it is presented in Table 1. In Table 1 the description of the specific objects, properties and relationships is listed in the first column, and the corresponding standard representations are shown in the remaining columns. For example, “Cable connector” is a specific object and “Item” is an entity in the standard AP 214 to represent a “Cable connector”. With AP 214, a group of other entities can be used to further classify the generic item as the specific object e.g., “Cable connector” but only the main entity e.g., “Item” is shown in Table 1. Based on the evaluation the answer to the two main questions posed in chapter 5 is: no, not all of the objects, properties and relationships can be represented by the standards AP 225 and IFC. But still, these standards can be used as a base for the factory layout representation. AP 214 is the only standard that can represent all the objects, properties and relationships in this study.

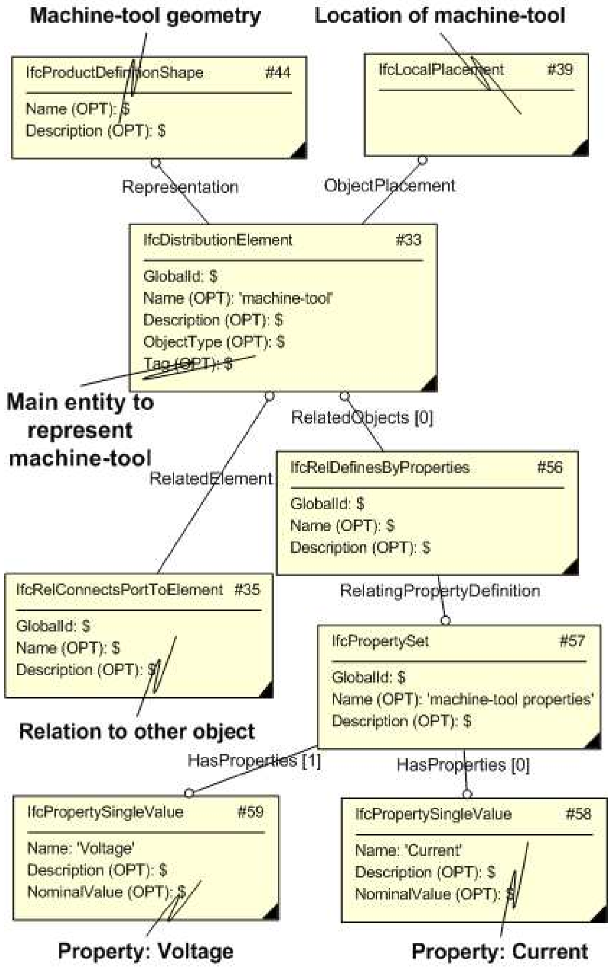

Figure 3: A simplified instantiation of IFC to represent machine-tool

7.1 Option one

Use only AP 225 to represent the three main domains: the manufacturing system, media and building construction. The main reason to use AP 225 is that it is a domain specific AP with building and media specified.

Advantages

- AP 225's complexity is lower compared to AP 214 and IFC, which means that it is simpler for implementers and developers.
- It is a domain specific AP with building and media specified. There are fewer requirements for an external concept model or classifications since many domain specific concepts are already in AP 225 and thereby minimise the need for some other concepts in an external concept model.

Drawbacks

- AP 225 is not so widely used compared to AP 214 and IFC. (The development of AP 225 has been inactive for years.)
- AP 225 does not include the representation of processes as AP 214 and IFC do.
- The information model lacks the ability to represent some information e.g., a manufacturing system and its relationship to a building. This is because AP 225’s focus is on building construction with its geometry representation. In short, AP 225 needs to be extended in order to support factory layout design and this extension work can be comprehensive and time consuming.

Option two

The second option is to use only AP 214 to represent factory layout. The main reason to use AP 214 is that it can represent objects, properties and relationships in this study with its generic character.

Advantages

- AP 214 is a generic standard uses the classification method to classify the objects and properties. It can refer to external domain specific classes to define entities. The classification can be based on standards or other classification systems. When the classification is completed and standardised it can be reused.
- AP 214 can represent all three domains in factory layout. The product design and process planning, etc. is also within the scope of AP 214.
- AP 214 is one of the most widely used APs [5].

Drawbacks

- Defining the class library can be time consuming due to needs of developing domain specific classification to fully utilise the capability of generic data models.

7.2 Option three

The third option is to use AP 214 to represent manufacturing system information and AP 225 for building construction and media information. Then implementations of these two APs can be connected as they share the generic information model of STEP. This option is proposed mainly because of the fact that AP 225 has more domain specific concepts and relationships which make it easier in representing buildings with its service systems whereas AP 214 is more suitable for representing machine-tools. Service systems are those systems that aim to serve manufacturing systems and the buildings, and are many times called media systems. This cross AP option makes the information (data) model more complex and further research need to be carried out.

7.3 Option four

The fourth option is to use only IFC to represent factory layout. IFC is a standard with a main focus on the buildings with its service systems. The IFC is more

Concepts in factory layout design	AP 214 (ARM)	AP 225 (ARM)	IFC2x4
Cable connector	Item (with classfication)	Service_element	IfcDistributionPort
Foundation	Item (with classfication)	Structure_enclosure_element	IfcSpace
Machine centre	Item (with classfication)	Service_element	IfcDistributionElement
Footprint	General_feature	-	IfcShapeRepresentation (with representation identification)
Geometry of electrical port	Shape_element	Component_shape	IfcProductDefinitionShape
Functional relationship between electrical cabinet and cable	General_item_definition_relationship	-	-
Location	Cartisian_point	Gis_position	IfcLocalPlacement
Relationship between cable voltage and electrical cabinet voltage	Property_relationship	-	-
Cable connector property: voltage	General_property (with classfication)	Property	Pset_DistributionPortTypeElectrical

Table 1: Example of detailed evaluation based on the three issues

complete and domain specific compared to AP 225 which also has a focus on buildings and its service systems.

Advantages

- It is a domain specific information model with domain specific concepts related to building and service system which means requirement on classification is less within these two domains.
- It is a well known standard in the building sector.

Drawbacks

- The growing numbers of versions of IFC with many changes make the core information model less stable and increase the work in software development [14]. The version used in this study is IFC 2x4.
- IFC has issues regarding the representation of manufacturing resources e.g., machine-tools, conveyers and robots. A direct representation of these is not possible, see Figure 3.
- IFC has difficulty representing relationships between properties.

8 CONCLUSION AND DISCUSSION

The evaluation of the three standards is performed. The results, answers and options are given, and the details are exemplified. Even if the details described in the three domains can mostly be represented by the standards, the representation path or quality can vary depending on how they are represented in the standards. E.g., electrical port for the electrical cabinet is easier to represent in IFC than in AP 225 and AP 214. The reason is that in IFC the entity electrical port is predefined while in AP 225 and AP 214 the entity is not predefined. Another example is machine footprint. The IFC standards has specifically pointed out that the “IfcFurnishingElement” has the attribute “footprint” but this footprint represents only 2D outline of the item [15] while the factory layout domain needs footprint that can represent different types of footprint scenarios and some of them need 3D shape representation.

Concluded from the evaluation, AP 214 has the best ability to represent all the details due to its generic character and that IFC is the most domain specific standard due to its domain specific concepts, see Figure 4.

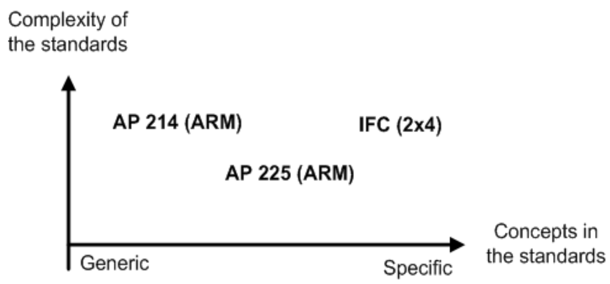

Figure 4: Character of evaluated standards

However, this does not make AP 214 the most suitable standard for factory layout design domain in the near future because there are other standards which are not yet evaluated and the classification work is not yet accomplished. The classification work is time consuming and knowledge requirements are high on developers. But for a longer perspective a classification work and development of a reference data library such as in ISO 13399 *cutting tool data representation and exchange* is very important for the future of factory layout design. This work then can be then used for many purposes not only enriching AP 214. One application is to have it integrated with the “Production Pilot” (described earlier), for a unified understanding of information in the factory layout design activities and better factory design support.

One way to minimise the classification work in AP 214 is to use the concepts in IFC as domain specific concepts and classification to enrich the information models in AP 214. An example of this is done for the "site" concept, given in Figure 5. The IFC entity "IfcSite" is used to classify entity "Item" in AP 214. In the similar way the properties in the "Pset_Sitecommon" can be used to classify the "General_property" from AP 214.

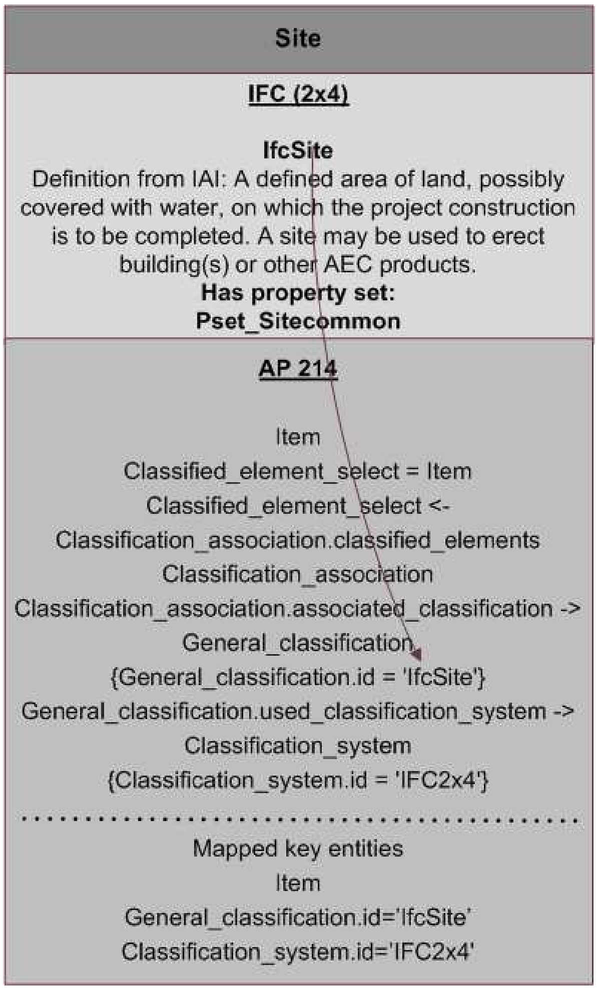

Figure 5: Using IFC concept and definition to enrich AP 214

Other standards such as ISO 10303 AP 239 Product life cycle support (PLCS) also have been considered as options but unfortunately they are not preferred for several reasons. PLCS is developed to be able to represent any complex product during its entire life cycle [16]. As an extension to this standard, there can be reference data libraries with external classes of more domain-specific concepts. By referring to these external classes, the standard can be further specialised into specific areas such as machine tools [17] or factory layout design. This means PLCS requires a reference data library for factory design which is not yet developed.

However, compared to the needs of factory layout design, PLCS demands an unnecessarily heavy system load to meet the requirements of factory layout design. Another issue with PLCS is that it does not support representation of geometry elements related to properties in a detailed level which is required by factory design.

There are also some other standards within the STEP family that can considered for future evaluations. These are AP 227: Plant spatial Configuration and AP 231: Process Engineering. STEP AP 241 for AEC (Architecture, Engineering and Construction) facilities is under development by ISO TC184 SC4. It started several years ago. The ISO 15926: "Industrial automation systems and integration—Integration of life-cycle data for process plants including oil and gas production facilities" is also a standard that can be considered in the future.

However, this study is performed on existing standards with a focus on what factory designers need to know to develop and realise a factory for the manufacturing industry. This is necessary due to the needs in the domain as described earlier. By comparing and evaluating these standards, a better overview on what these standards can represent in the domain of factory layout design is summarised.

All the options above have their advantages and drawbacks. This study shows that option two and option four are most preferred because these two requires less comprehensive work comparing to other two options which include the extension of standards. The choice can vary depending on the work situation and the focuses within the factory layout. The factory designer is the interface between the manufacturing domain, media domain and building domain. These three domains sometimes can be very far away from each other, especially the building domain and manufacturing domain. There are two main questions related to the system usage and development that need to be answered:

- If it is important to be compatible with others in the manufacturing area. STEP is well-known compared to IFC in the manufacturing area, which means that STEP is more publicly acceptable in this area. It is always easier to develop something well-known. Unfortunately in the manufacturing community, STEP is mainly known as a file format able to exchange 3D geometry and assembly structures.
- If it is important to be compatible with the building construction domain in the future. IFC is better known in the construction domain than STEP which means it will be accepted more easily. This file format is known by many in the construction domain.

9 ACKNOWLEDGMENTS

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