



**KTH Industrial Engineering
and Management**

Information Management for Factory Planning and Design

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Doctoral Thesis

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To my mom and dad for their endless support

Abstract

This thesis is dedicated to the manufacturing industry for the improvement of information management within the factory planning and design domain, and for more efficient factory planning and design. Currently the manufacturing industry lacks sufficient methods for capturing, structuring, and representing information and knowledge for easy access, exchange, integration and reuse within the domain. Therefore the focus of this thesis is on information and knowledge management within factory planning and design, which involves two subjects; information management and factory planning and design.

In this thesis information and knowledge are captured by different models for different purposes, with the viewpoint of the factory planner and designer. A concept model is developed for a unified understanding of terms. An activity model is developed to define the domain scope, information flow and is used as the core of the factory planning and realization pilot, which is also developed. Information models from different information standards have been evaluated for a future common information platform within factory design. Principles about how to apply standards and concept models to the factory design are presented and discussed.

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Much of this I have said before and I say it once more, because I couldn't find better words.

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Stockholm, December 2011
Danfang Chen

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Software Tools for the Digital Factory – An Evaluation and Discussion

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

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APPENDED CONCEPT MODEL

Concept model for factory layout

APPENDED PROCESS MODEL (FOLD-OUT)

Factory planning and realization process – detail level

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1 Introduction

1.1 Background and motivation for the research

This thesis is a result of the research projects ModArt (Model Driven Part Manufacturing) and Factory Design Process, which are dedicated to the Swedish manufacturing industry, to supporting them with better information availability, reuse and utilization, within production system development.

The industry is continuously improving their manufacturing systems through e.g. upgrading a manufacturing line, buying machine-tools or developing new factories. The reasons behind this can be many, such as a new product introduction in the factory or an increase of capacity to meet the market demand. According to U.S. Census since 1955, approximately 8% of the USA's GNP (Gross National Product) has been spent annually on new facilities and of this 3.2% is for the manufacturing industry (Tompkins, et al., 2010). Investment in buildings and machines within the Swedish industry was estimated to 72.9 billion Swedish kronor in 2008 (SCB, 2008), see Figure 1.

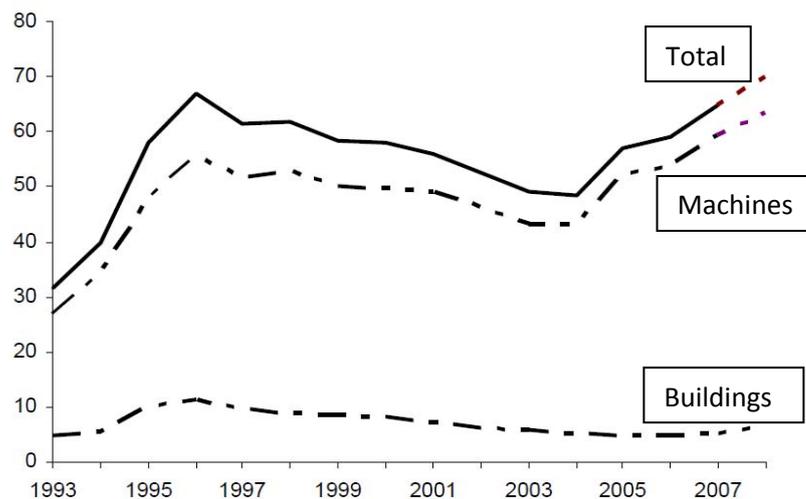


Figure 1 Industrial investment in Sweden 1993-2008, (SCB, 2008)

Most factory planning projects include investments in machines and buildings but the expenses are not limited to these. In order to control the cost and process performance at an early stage of investment, different kinds of support are needed, such as reference process models in factory planning, for better structured project work and better informed decisions.

Currently manufacturing companies face many problems in factory planning and lack a systematic way to run factory planning projects. Companies are using simple tools, such as Gantt Charts, together with their own established principles, methods and directives to run factory planning projects. During the ModArt research project, various companies in Sweden were visited and interviewed. None of them had a systematic way of doing factory planning. It is instead common to fully rely on people that have participated in a factory planning project before. A reference process model for factory planning with the possibility of integrating company specific project model to support the projects is missing. Applications within different areas of expertise are used during the factory planning to help develop the result. Applications for factory layout design, flow simulation, and plumbing design, are a few examples. Often the results from these applications are difficult to combine.

Current main situations/problems within factory planning and design, which need to be addressed are:

1. **What-to-do and how-to-do information for factory planning is scattered.**

This makes it hard to follow the information flow and difficult to find all the related information. Information can be spread out in various documentations in different places, and frequently is only to be found in people's minds. For example, at Scania this kind of information is stored in many places, amongst others, the company's own technical regulation handbook, production equipment investment process handbook, layout requirement guideline for suppliers, individual's minds etc. More background in Chap. 3.1.

2. **Information about resources within a factory, needed for the development of factory design, is scattered or missing.**

It is difficult to find and integrate information when it is stored by different people in different application files and folders. This information can be machines' weight, safety regulations, foundations load carrying capacity and more. More background in Chap. 3.2.

3. Geometrical models of machines and buildings are saved in different application formats.

This makes it difficult to integrate geometrical models for a whole system which can be a factory, a manufacturing line, a manufacturing cell and more. More background in Chap. 3.2.

A non-streamlined factory planning process or a mistake in factory layout design can delay a project by months, and a small error in geometrical model integration can result in a direct cost increase.

This thesis addresses these problems and has its main focus on overall information management in factory planning and design, in the form of information reuse, availability and utilization. The focus involves two domains: the information management domain and the factory planning and design domain.

Currently information management related to different manufacturing areas e.g. factory planning, have become a very important topic due to the world is in a digitalized era with rapid and dynamic changes. In roadmap of ManuFuture (Westkämper, 2009) and keynote from CIRP (Tolio, et al., 2010), digital factory and knowledge-based engineering have been pointed out as enabling technologies for the next generation of manufacturing, both of these related to information management within factory planning. Many research projects have in part focused on information management within factory planning such as Virtual Factory Framework (VVF) (Pedrazzoli, et al., 2007) and Digital Factory for Human Oriented Production System (DiFac), (Sacco, et al., 2007).

1.2 Vision, research objectives and research questions

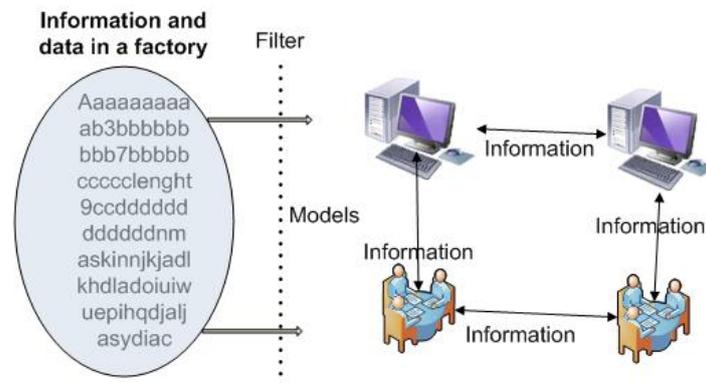


Figure 2 Different communication situations

The vision:

There are different communication situations in factory planning, these are: between computers, between humans, and between computers and humans, see Figure 2. For all different communication situations, the goal is to get the right information within the required time by using the right models.

In the vision there is a factory planning and design domain specific concept model for a unified understanding of terminology between domain experts, see Figure 3. During the planning and design there are many experts from other domains involved, these experts usually have their own definitions of the concepts and terms which may lead to misunderstandings.

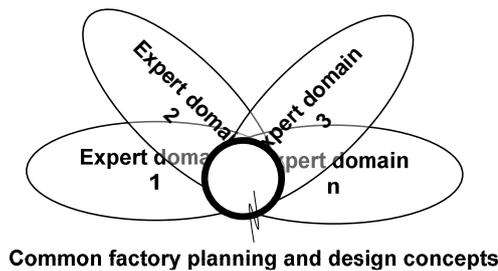


Figure 3 A common factory and design concept model for different expert domains

In the vision there is a sustainable information platform which can easily store, access and integrate information from different applications used by different domain experts, see Figure 4. This information can be geometrical models of the different resources and other non-geometrical information about the resources and processes. Figure 5 is an illustration of this part of the vision, although with one machine. In this illustration, the machine is modeled from the viewpoint of a factory designer, which means that the information in Figure 5 is needed by a factory designer to develop a factory layout.

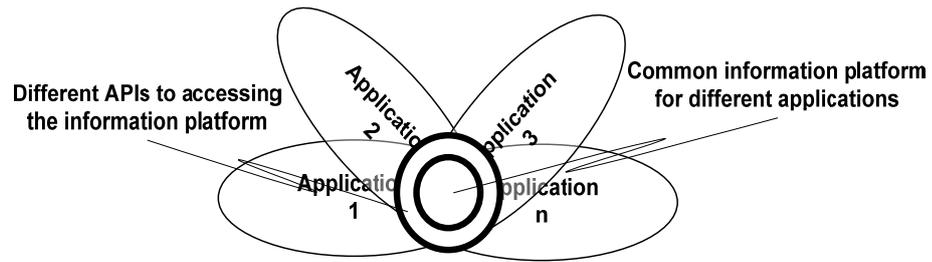


Figure 4 A common information platform accessible for different applications

The four most important criteria for a sustainable information system are (Al-Timimi, et al., 1996):

- Extensibility, ability to extend and represent a variety of data types.
- Longevity, the data should outlive the software and hardware on which it was created.
- Portability, ability to move data among applications.
- Interoperability, ability to share data between applications.

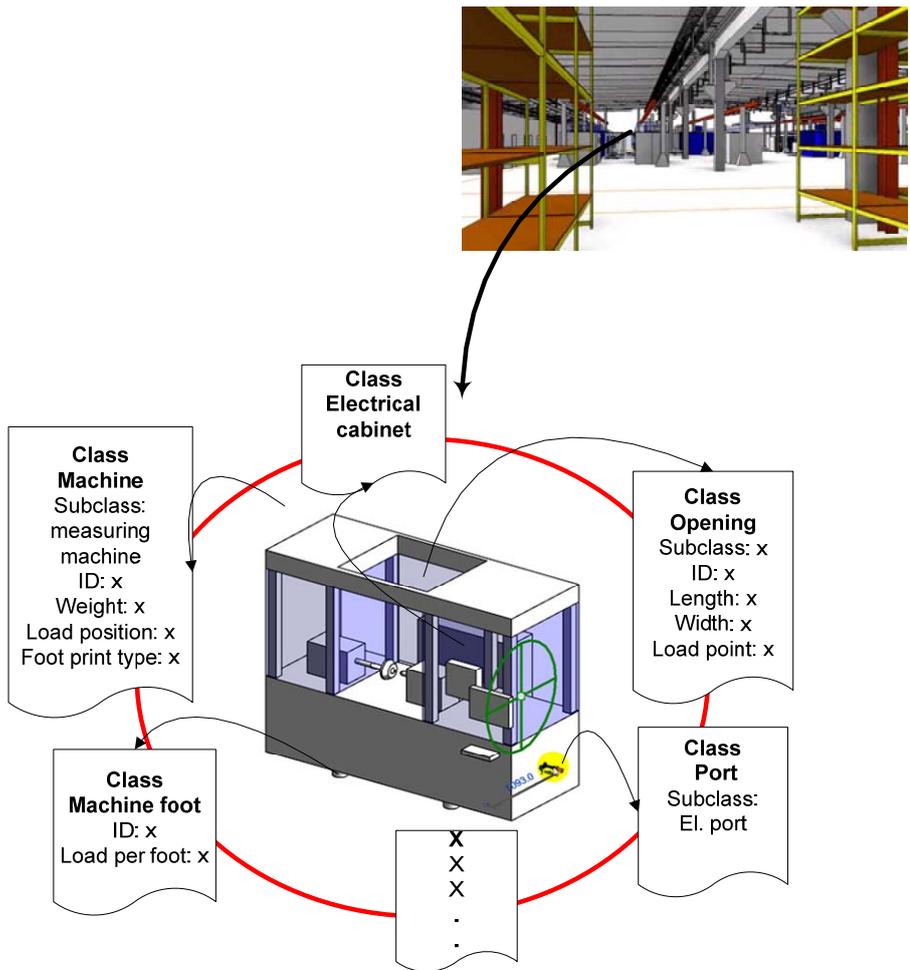


Figure 5 A machine model from the viewpoint of a factory designer

In the vision there are reference process models with guidelines for different expert domains, integrated with different applications to support experts to do the right things and make the right decisions, see Figure 6. The reference process model with guidelines will provide experts with what-to-achieve information e.g. a factory layout model, how-to-achieve information e.g. descriptions of the work, and why-to-achieve these e.g. laws and standards. In the vision the integration is made possible by the unified concept model.

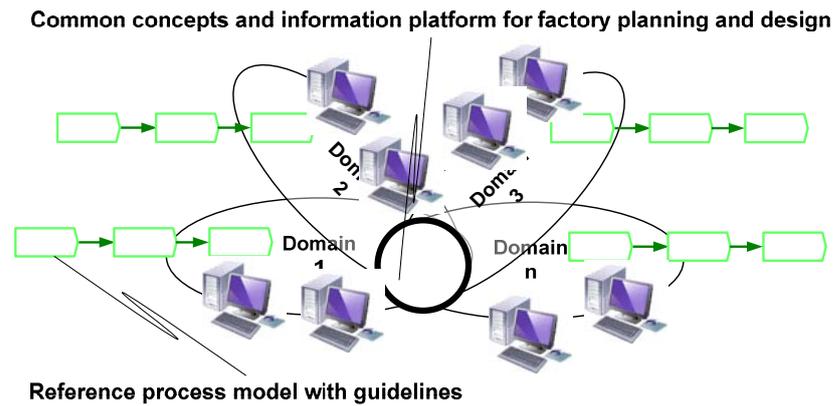


Figure 6 Reference process models with guidelines for expert domains, integrated with applications

To accomplish this vision, the following objectives have to be fulfilled and research questions need to be answered.

The objectives based on the vision:

1. To realize an information platform for factory design.
2. To realize reference process models with guidelines for factory planning and design, to guide people with required information.
3. To realize concept models to integrate the human experts and their applications, i.e. to integrate the information platform and the reference process models with guidelines for the different experts.

The research questions based on objectives:

For objective 1:

- What information ought to be represented in a factory design model – in an information platform for factory design?
- How can the information in the platform be created and made available in different applications?

For objective 2:

- What are the activities involved in factory planning and design?
- What information is needed about the activities in factory planning and design, i.e. information about what-to-achieve, how-to-achieve and why-to-achieve?

For objective 3:

- What are the important common concepts and applied terms in factory planning and design?
- How can the concepts be utilized to realize the integration?

1.3 The thesis structure and publications

Each part of this thesis is written with a purpose and Figure 7 offers an overview of the relationships between these parts and publications.

Generally, Chap. 3.1 provides the main background to the production planning and realization pilot. Chap. 3.2 provides the background to why the factory design domain needs principles for how to apply standards and concept models. Chap. 3.3 describes why a “model based” approach is selected for this research and Chap. 3.4 describes reasons for using standards as information architecture for a factory design information platform.

In Figure 7 some of the parts are not linked to others, because these provide background information to all the parts. More details about the relationships between the various parts and publications can be found in Figure 7.

Publications:

PAPER A: A Concept Model for Factory Layout Design

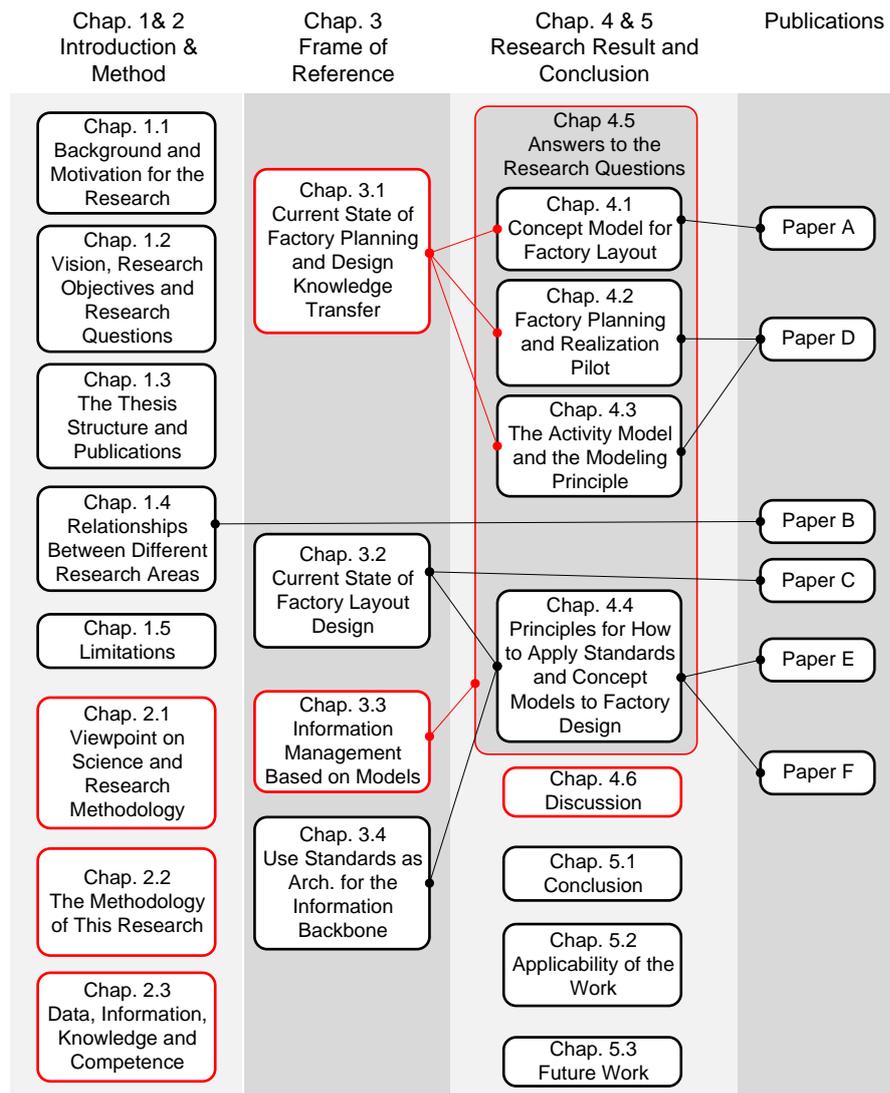
PAPER B: The Digital Factory and Digital Manufacturing – A Review and Discussion

PAPER C: Software Tools for the Digital Factory – An Evaluation and Discussion

PAPER D: Production Pilot for Co-operation in Factory Development

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

PAPER F: An Information Communication Approach for Factory layout



Different colors are only used for increased clarity

Figure 7 Relationship between the thesis parts and publications

1.4 Relationships between different research areas

It is important to see the relationships to other research for a better understanding of this research. Figure 8 tries to give an overall view of these relationships, and a more detailed description of each part can be found below.

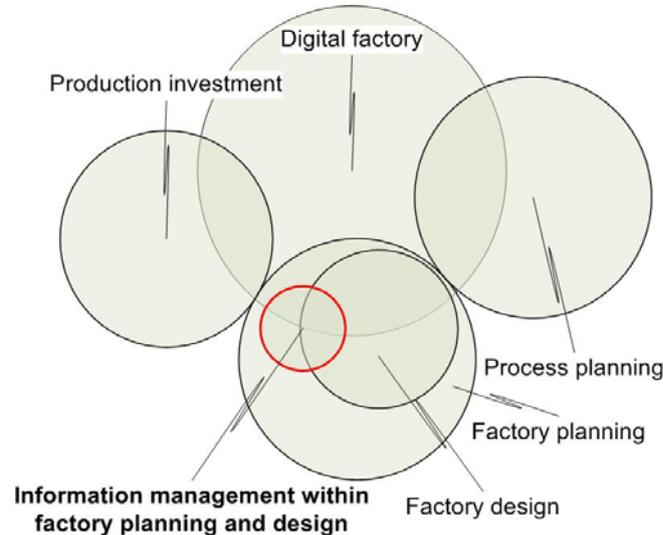


Figure 8 Relationships between different research areas – a conceptual picture

Within the factory planning and design domain:

In this thesis factory planning and factory design are distinguished.

Factory planning:

Factory planning covers all activities in the fold-out, except the installation parts, when developing a (new) factory. It extends from investigating the feasibility of the factory project within the time and cost limitations to preparation of installations. For a deeper understanding and explanation see the activity model in the fold-out, and the factory planning and realization pilot.

Factory design:

The factory design process is a part of the factory planning and it only concerns the design part. The project management, the logistic part etc. are not considered here. The main result from the factory design is the factory layout, therefore many parts of this thesis have their focus on factory layout design.

Information management within factory planning and design:

This part focuses on the information that needs to be managed within factory planning and has a deeper focus on factory design. Information management in this research is not about PLM (Product Lifecycle Management) as many people will relate to. Information management in this research means how all the information within a domain can/should be organized, structured, represented and presented for the best use and reuse, both for humans and applications. This is also the foundation for a good realization of PLM or rather MLM (Manufacturing lifecycle management) in this case.

Factory layout:

Many researchers are doing research within factory layout but the focus has mostly been on positioning of resources such as process-oriented layout and functional-oriented layout (Andreasson, 1997), (Tompkins, et al., 2010). In this research factory layout has a broader focus, it is not only about the positioning, it is also about the information needed to develop a factory layout. Factory layout can be manufacturing system layout, building layout, painting layout see Figure 9, or safety layout see Figure 10 (Chen, 2009). In Figure 9 and Figure 10, the layouts are developed only with geometry and the rest of the information, such as types of area and emergency stops, are added in the layouts afterwards i.e. this information is not represented in layout, only presented.

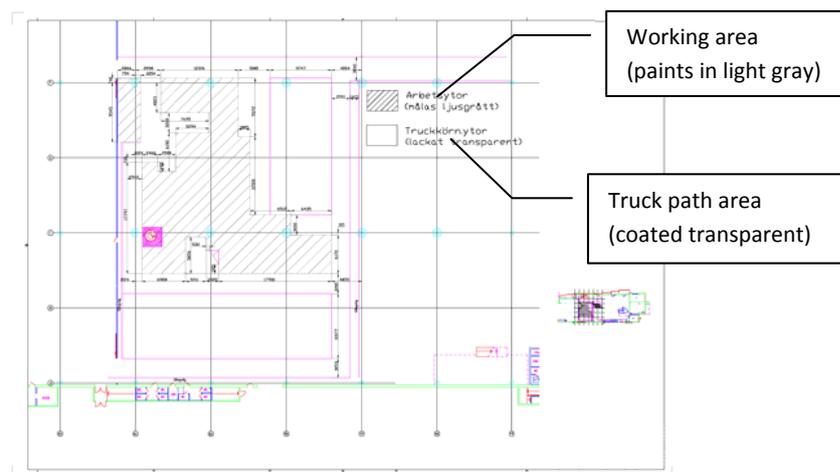


Figure 9 Example of painting layout with added text information

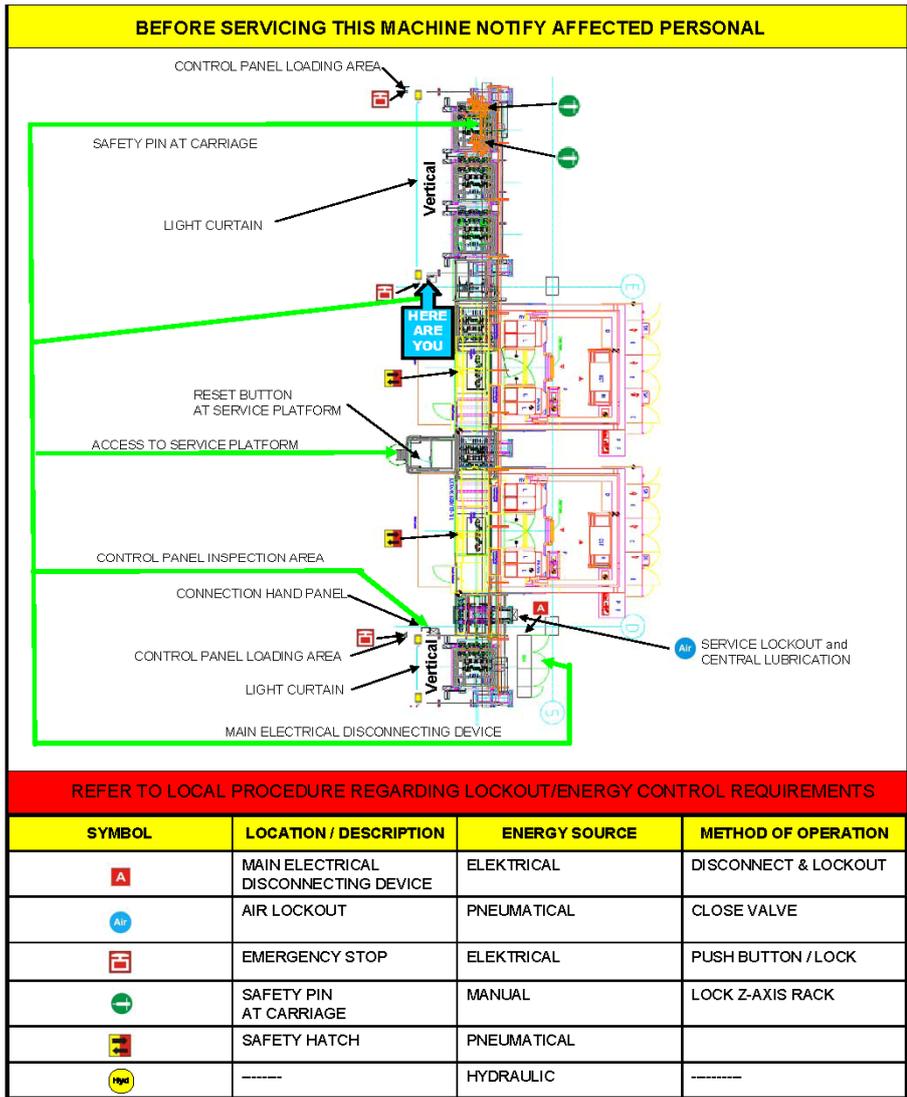


Figure 10 Example of safety layout from Scania with added text information

Other research within factory planning:

There is a lot of research within the factory planning and factory design domain which is not in the focus of this study, e.g. flow simulation, scheduling and optimization for fine tuning of the layout. Parts of this research result can be used to support these activities.

Outside of the factory planning domain:

During the manufacturing system development, the factory planning domain is closely related to production investment and process planning. These three domains, for a certain level of detail, go hand in hand with each other in order to give the best result. E.g. to design a layout in factory planning, the information about the process sequence from process planning and new machine size from production investment is essential (Chen, 2009).

Production investment:

Production investment focuses on the equipment and communication with equipment suppliers, in most cases the equipment is machines. The production investment process helps to quality secure the machine tool investment process. More details can be found in (Larsson, 2006).

Process planning:

The focus of process planning is how a part or product should be manufactured in a machine or a manufacturing system. The planning handles the selection of the right type of process, sequence planning, measurement planning, appropriate fixture design etc.

This research as part of a bigger research - the digital factory:

Although this research is not mainly focused on the digital factory, parts of this research result will be a core part of the future digital factory information platform. These parts are the concept model for factory layout and the principles of how to apply standards as architecture. The digital factory will be the information backbone for the factory of the future, with its resources and processes during its life cycle. The factory design information platform is a part of this backbone. The digital factory concept is discussed in paper B and paper C.

In short, the digital factory should reflect the real factory at a certain level of detail, and real time information from the real factory should be used to update the digital factory. Real time information can be key performance indicators from different monitoring systems that are connected to models in the digital factory. By simulating the digital factory, people can see the change in performance before implementation and in this way the real factory can be continuously improved.

1.5 Limitations

- The concept model, the activity model and the pilot are developed based on information about machine-tool factories, which is a limitation.
- The development of factory design applications is outside of the research scope.

2 Research method

2.1 Viewpoint on science and research methodology

Popper K. and Chalmers A. F. are some of the famous names within philosophy of science, and their view on scientific methods such as induction and deduction (Chalmers, 2003) and falsification (Popper, 2008) are widely spread.

Sometimes within production engineering it is difficult to apply one scientific methodology and strictly follow it, due to several reasons e.g. the close relationship and collaboration between academia and manufacturing industry. This relationship means that the research needs to have a profit and productivity aspect. Still, it is important to create a solid foundation for achieved results through applying a scientific approach and methodology.

“The scientist explores what is, the engineer creates what has never been”, by Theodore von Karman (Sohlenius, 2000) is a good way to see the difference between science and engineering.

In addition to production engineering, this research also has a part in information modeling. Sometimes it is also difficult to apply such methods as induction, deduction and falsification fully to this domain, because the models (e.g. concept model, activity model and information model) in this research are developed to suit a specific purpose and view. But to apply general theories, general rules or general truths from e.g. induction and deduction methods is still important.

However, researchers in engineering have their own understanding and viewpoint on science, such as G. Sohlenius, who proposed the paradigm of the science of engineering inspired by Theodore von Karma with the following steps: the engineering scientist analyzes what is; imagines what should be; creates what has never been and analyzes the results of the creation (Sohlenius, 2000).

2.2 The methodology of this research

A mass of data and information is collected from academic research and companies, especially Scania and the other companies in the ModArt project. The data and information related to factory planning and design are collected through interviews and meetings with experts, through participation in the daily project work and visits to equipment suppliers, these interviews and meetings are estimated to be more than 300. Many of these interviews and meetings have focused on:

- The important issues which need to be addressed.
- The needed information for the activities, the relationship between activities and information.
- The important concepts used in the domain and their meaning.
- The expected hopes and achievements etc.

Important documentation related to the area of factory planning at Scania and academy has been studied such as research papers, requirement specifications for machines-tools, meeting protocols from factory development and safety standards. Data and information has been gathered continuously during the years, in order to cover most of the area.

During the data and information collection, general problems and needs are understood and identified. From these, the research questions, research objectives and vision are formed. Then a generalized concept model for factory layout, an activity model for factory planning and realization, and a pilot for factory planning and realization are developed. In other perspectives, the gathered and studied information is documented in different ways:

- One part is documented in the vision, objectives and research questions.
- One part is documented in the concept model for factory layout.
- One part is documented in the factory planning and realization activity model.
- One part is documented in the factory planning and realization pilot.

These developed models and the pilot are then tested and verified by experts and real ongoing factory development cases from industry. The experts have been selected based on these criteria:

- They have the factory planning and design task as a daily work.
- They have been working within the factory planning and design area more than 10 years.
- They have participated in the development of productive factories.

Based on vision, objectives and research questions various information standards have been selected for evaluation. Based on the developed concept model, activity model and pilot, the evaluation of selected information standards are performed and principles for how to apply standards are formed. The related applications within factory design have also been evaluated during the research. This is in order to gather the knowledge about the state-of-the-art applications, to identify the problems and to verify the vision.

The science of engineering method from G. Sohlenius has been followed (see Figure 11) and applied through induction and deduction theories.

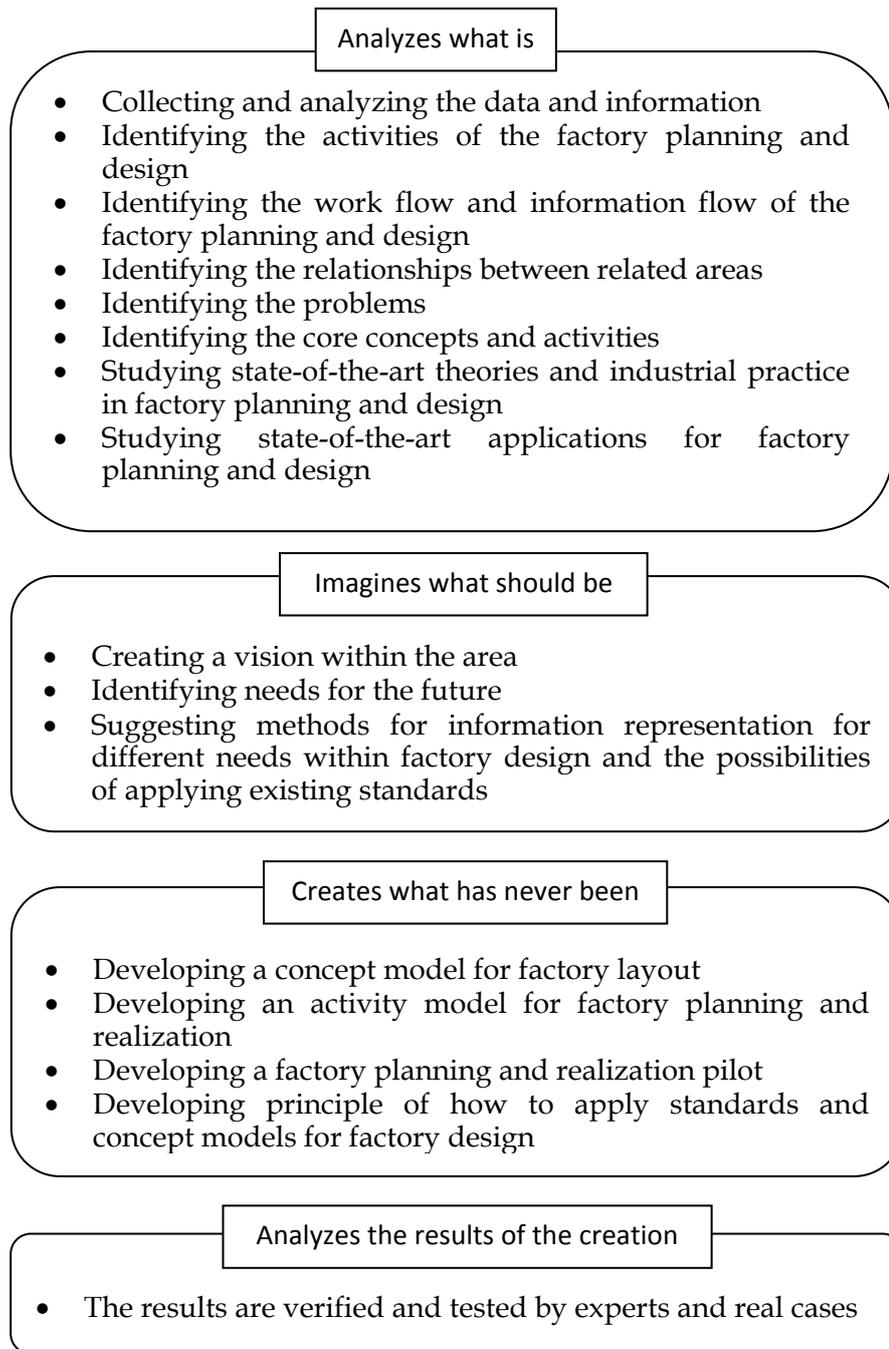


Figure 11 Working steps followed by science of engineering method from G. Sohlenius

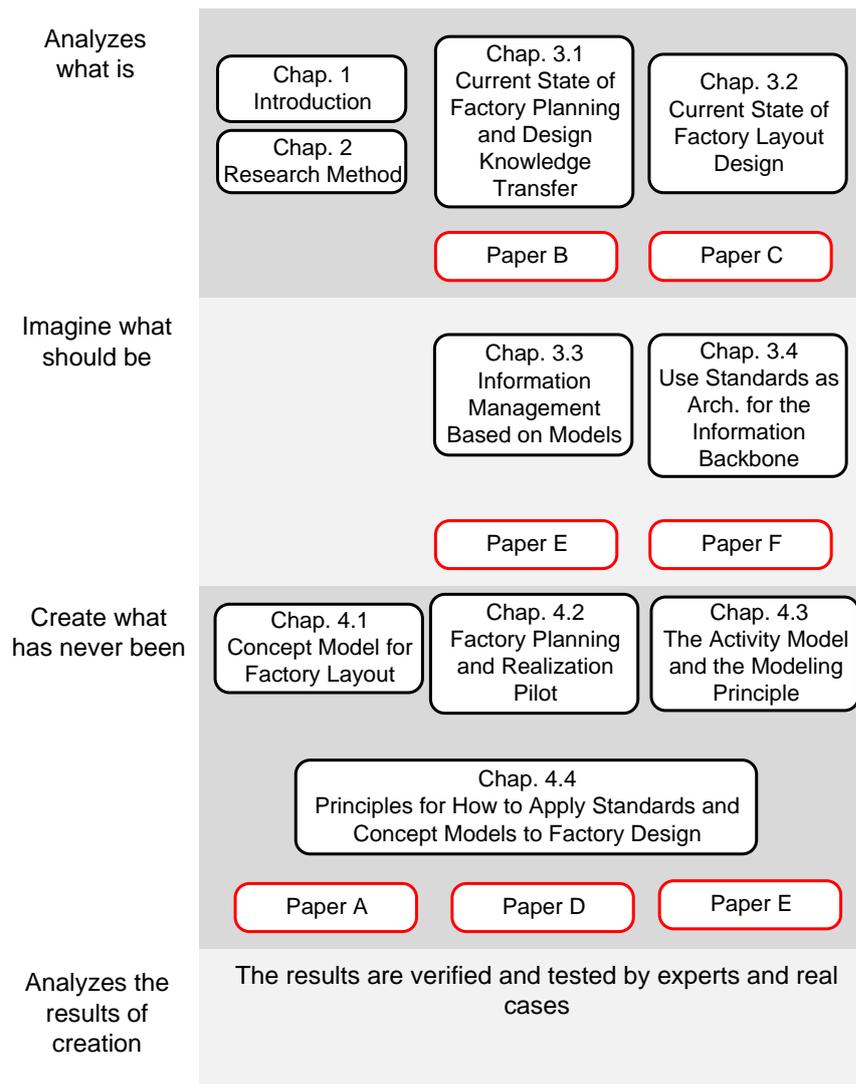


Figure 12 Relationship between research steps, publications and contents in the thesis

Figure 12 shows how the parts and publications in the thesis are related to research steps from paradigm of science of engineering.

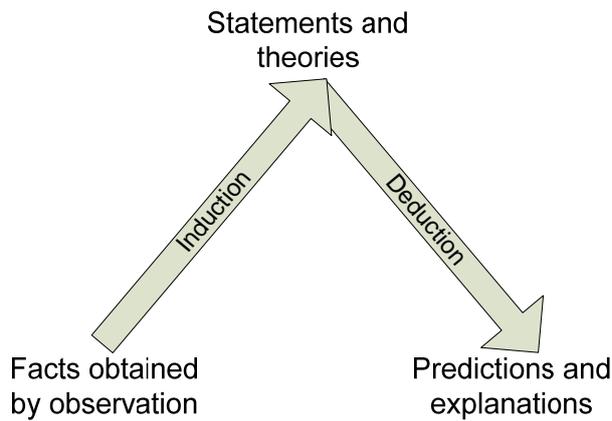


Figure 13 Induction and deduction, adopted by Chalmers (Chalmers, 2003)

The general steps of this research can be identified with the induction and deduction method in Figure 13, model (theory) forming by induction and then model (theory) testing by deduction. The flow of this research can be mapped into these steps, as follows:

- Model forming by induction:
 - Observation of the real world for understanding the factory planning and design domain by information from industry and academia, identify the problems and observe the needs.
 - Detect the pattern of factory planning and design information from the real world.
 - Form the vision and suggest methods for information representation.
 - Develop the general concept model for the factory layout and activity model for the factory planning and realization. Create the pilot for factory planning and realization. Develop how to apply existing standards to represent factory design information together with a domain specific concept model.
- Model verification by deduction:
 - Verify and test developed models and pilot with experts and test cases from industry.

2.3 Data, information, knowledge and competence

Working within the information management domain the differences between data, information, knowledge and competence need to be reviewed and defined. Below are some definitions which are relevant to this research.

Information exists when the relationships between data are recognized within a specific context and the knowledge is information with added detail relating to how it should be used or applied (Cochrane, et al., 2008).

Knowledge is *“a mix of expertise, experience, process, conceptual information and insights that provides a framework for decision-making or problem-solving”* (He, et al., 2009).

Competence means having knowledge and practical ability to perform, only with the right competence can the knowledge then form the basis for a good decision or action (Kjellberg, et al., 2007).

3 Frame of reference – Information management within factory planning and design

3.1 Current state of factory planning and design knowledge transfer

Factory planning is a knowledge intensive process which no one can handle by themselves. The process is complex and involves many domains, generally these are: the manufacturing domain, media domain and building domain.

The current state of knowledge and information transfer to factory planning documentation from industry is poor in Sweden. The existing documentation only handles parts of the whole factory planning, e.g. *Handledning i Verkstadslayout* (Andreasson, 1997) or company specific documentation that also only handles parts of the factory planning, such as PEIP (Production Equipment Investment Process) from Scania. The most normal knowledge transfer is PTP (Person To Person) which means that an inexperienced person asks an experienced person for advice. This PTP method has disadvantages such as information singularity, information inaccuracy and information unavailability.

Internationally, factory planning has a long history in the engineering domain, the first industry engineering text book “*Factory Organization and Administration*” was already published in 1910 (Heragu, 2006). Over the years lots of books, e.g. “*Facilities Design*”(Heragu, 2006), “*Factory Planning Manual*” (Schenk, et al., 2010) and “*Facilities Planning*” (Tompkins, et al., 2010), have been published in order to support the factory planning process in different ways. The focus of these books is mostly on specific methods and areas within factory planning and design.

Even though many books are written about methods and descriptions of the important activities, the detail descriptions about what-to-do and how-to-do are not available. The relationships between the activities are not as clear and detailed as those in the activity model for factory planning and realization (fold-out).

According to Tompkins (Tompkins, et al., 2010), the winning facility planning process, with its overall facility planning steps involves the following activities:

1. Understand the organization model of success
2. Understand external and internal issues
3. Establish facilities planning design criteria
4. Obtain organizational commitment
5. Establish teams
6. Assess present status
7. Identify specific goals
8. Identify alt. approaches
9. Evaluate alt. approaches
10. Define improvement plans
11. Implement plans
12. Audit result

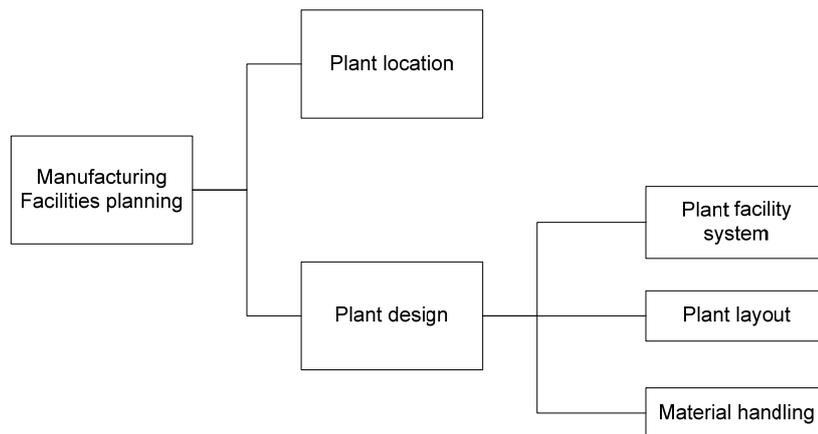


Figure 14 Overall facility planning steps (Tompkins, et al., 2010)

There are also many research papers published within factory planning and design such as (Constantinescu, et al., 2011), (Viganò, et al., 2011) and (Iqbal, et al., 2001). The main focus of these papers is on specific methods, specific issues and specific parts of factory planning. It is difficult to capture a full picture of the factory planning process with its details in a paper.

3.2 Current state of factory layout design

The factory layout is considered as the core result of the factory design process. During the development of the factory planning and realization pilot in the ModArt project, it was identified that the layout development is the essential activity in factory design. The essentialness of layout development has also been pointed out by

many other researchers, such as (Weimer, et al., 2008) and (Kim, et al., 2009). A well planned layout is essential during the realization phase and for the operational phase of a factory.

In this research the factory layout is a place where various results from e.g. material handling planning and process planning get integrated and visualized (it is in the factory layout that the physical result appears instead of a description in words and numbers). In other words, it is in the factory layout that the different domain information (geometrical and non-geometrical) of media, machines and buildings are merged together for a better overview and integration (Chen, 2009).

Different application tests have been performed within the research projects ModArt and Factory Design Process. Applications such as FactoryCAD, DELMIA Process Engineer, Navisworks, Revit Architecture and Factory Design Suite were tested. FactoryCad and DELMIA Process Engineer were tested by the author, and are described in Paper C. The test results show that none of the tested applications can integrate different domain information as it is. Detailed descriptions of integration are provided below:

Factory designer gets different geometrical models from different actors with their own design applications. Then the factory designer re-constructs the geometrical models from these disciplines and extracts other important non-geometrical information from different files to verify the factory layout, i.e. collision control, requirement check and more. This integration issue can be divided into several sub issues, such as:

- Wrong type of geometrical model for factory design. E.g. the machine-tool model is developed for construction of a machine-tool which contains information that is not necessary and lacks other information that is necessary. The factory designer needs a geometrical model that contains the right types of information, e.g. geometry of the machine-tool body contour, envelope area for the operation and service, position and orientation of connection ports and the foot-print of the equipment, one example is Figure 5 in Chap. 1.2.
- Many different file formats are used by different expert applications for factory layout design. This makes the integration of information difficult, and many times application dependent. The factory designers need an information system that can make applications collaborative, i.e. which can easily store, access, share, change and integrate information.

- The geometrical information is separated from the other information such as machine weight and required current. The development and verification work will be easier if these two types of information are integrated in one model.

These described layout design issues are issues which factory designers face many times during the design phase. Some related work has been done to solve these issues, e.g. in (Lucke, et al., 2008), (Weimer, et al., 2008) and (Hints, et al., 2011). A part of this work focuses on overcoming the application dependency problem by different methods, such as a common information hub (common information platform) between applications. But the common information hubs today are usually not based on an open architecture and have difficulties to provide solutions for the four most important criteria, as described in Chap. 1.2. If an information platform or information hub cannot fulfill the four criteria, then the system independency is only solved for the specific case during a limited period of time.

3.3 Information management based on models

To capture, understand and structure the data, information and knowledge within the domain, different models are applied for the best utilization. In other words, there are different ways to represent information for different needs. Due to the research questions presented earlier, the “model based” way has been selected in this research to improve the current situation and fulfill the vision. There is a belief that the model can reflect the relevant part of the reality and different models can reflect different perspectives of reality. Three model types (concept model, activity model and information model) have been selected to represent the different types of information. The relationship between these three models is that the concept model defines the knowledge of a domain, with the use of specific terminology, to be mapped out with the information model and the activity model.

The concept “model based” and “model driven” are used by various people in various contexts, below are three descriptions of them, all related to this thesis.

“Model based as that the information is always kept in context, versionable, possible to associate with other relevant pieces of information, e.g. features, and retrievable as properties or geometry through the model, not by reference to documents” the concept “model based” information described by (Nygqvist, 2008).

In software engineering: *“Model driven development is used frequently as a method to capture the information that specify the requirements of an information system to be built as well as the design and implementation of that particular information system”* the concept “model driven” development in context of information systems described by (Rosén, 2010).

According to Prof. T. Kjellberg: For model driven development in mechanical engineering, information in models forms the base for new information, and drives input from users and other models.

The concept “model based” in this thesis means that the information is captured and represented in different models for different purposes.

This section describes why these three model types are selected.

Concept model and concept modeling:

Concept is an abstraction, to write and speak about them, terms and definitions are needed (Suonuuti, 2001). Figure 15 is an illustration of the relationships between concept, term, definition and referent, exemplified with concept factory layout.

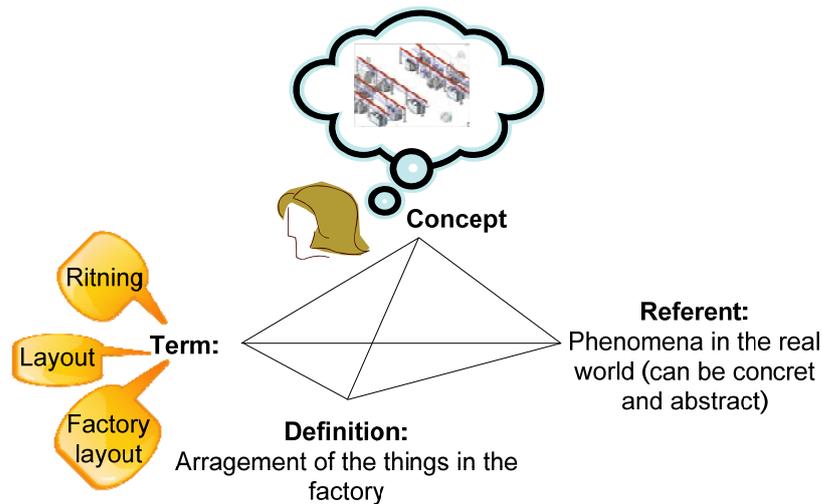


Figure 15 Relationships between concept "factory layout", term, definition and referent

Currently, different people and applications use different terms to express the same concept, or use the same term for different concepts. A concept model is then a good type of model to manage the meaning

of used terminology and capture the information within factory design. Therefore concept model is selected to represent the important concepts in factory design for a unified understanding and better reuse of information. The purpose of the concept model is to capture the most relevant “terms”, their underlying meaning in a domain as well as their relationships, and to give the terms consistent meaning.

A concept model can be in the form of ontology, taxonomy and more, because all these can explicitly describe concepts and the relationships between concepts in different ways.

A concept model can be modeled by many modeling languages such as Web Ontology Language (OWL) and Astrakan concept modeling method (a part of Astakan methods). OWL is used to develop an ontology that needs to be processed by applications (computer interpretable). Languages which can give computer interpretable models contain more predefined rules/elements to specify the information types.

The concept model in this research is based on the Astrakan concept modeling method, due to its simplicity. The purpose of this method is to capture concepts and their relationships for a unified understanding of the terms used in the domain. Due to its simplicity the concept model developed with this method cannot be processed by an application. This concept model can be used as a base for implementing the classification work by applying the Parts library (PLIB) - ISO 13584 standard. Within the PLIB the fundamental principles, implementation methods and methods for structuring concepts/terminology are defined which makes it computer interpretable and possible to map against an information model.

The main elements of the Astrakan concept modeling method are object type, relationship type, attribute, cardinality and specialization (Astrakan strategisk utbildning, 2011). Figure 16 shows the elements that are used in this thesis and exemplified in Figure 17.

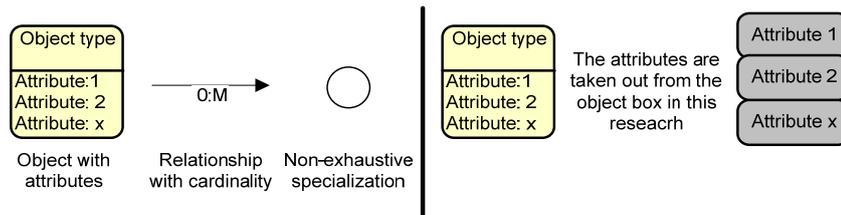


Figure 16 Elements of Astrakan concept modeling used in this thesis

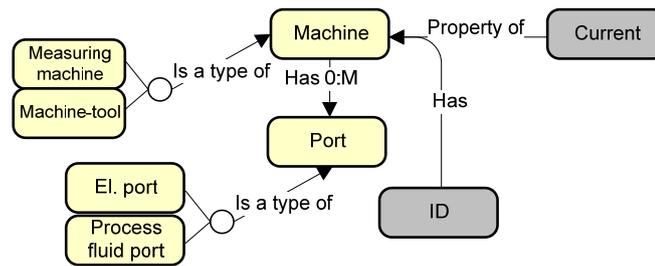


Figure 17 Concepts modeled by Astrakan concept modeling method

Information model and information modeling:

The information model in this research is used to capture all the relevant information within the domain and to work as an information specification to develop an information system. The purpose of the information model is to structure information, represent relationships between information and define information types.

In this research an information model is not developed, instead information models from information standards are evaluated for their ability to represent information required for a factory design information platform. The reasons for choosing information standards are described in Chap. 3.4. The information models in the existing standards are all described with the EXPRESS information modeling language which is a part of ISO 10303. To evaluate the information models within standards it is important to understand the EXPRESS information modeling language, but the EXPRESS elements and rules are not presented in here, they can be found in the documentation about EXPRESS ISO 10303-11 (TC184/SC4, ISO, 2004).

Definition: "Information modelling is the activity of identifying, relating, and structuring the information types that need to be managed into an information model."(von Euler-Chelpin, 2008)

Activity model and activity modeling:

The activity model is selected to represent the activities of a process and the relationships between those activities. The purpose of the activity model is to capture important activities and the information flow between activities and disciplines related to a domain, such as factory planning. Currently, the various disciplines related to factory planning have their own view on the factory planning content and sequence, which creates misunderstandings and unsynchronized

projects. The activity model defines the scope of the factory planning domain, streamlines the information flow within the factory planning process and acts as a foundation and specification for the domain specific information model development.

There are two activity modeling methods in the discussion, IDEF0 and the Astrakan process modeling method. These two methods are used as a base for the developed activity modeling formalizations described in Chap. 4.3. Both IDEF0 and Astrakan are based on, or derived from, the Structured Analysis and Design Technique (SADT), which is a well established graphical language developed by Douglas Rose (Marca, et al., 1988). The basics of SADT are ICOM (input, control, output and mechanism) which both IDEF0 and Astrakan have, and these are illustrated in Figure 18.

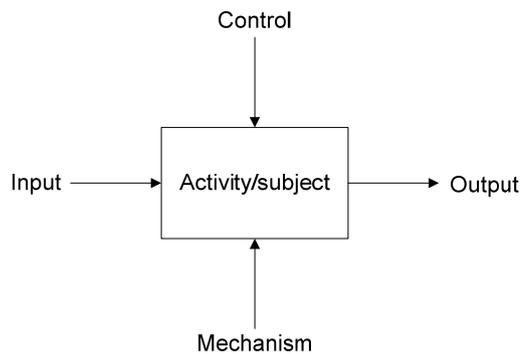


Figure 18 Basic SADT modeling

Integration Definition for Function Modeling (IDEF0):

IDEF0, a method developed by the National Institute of Standards and Technology (NIST) for modeling of a system, also a method used for creating a graphical representation of a system. IDEF0 can represent the decisions, actions and activities of an organization or system (Knowledge Based Systems Inc., 1993).

Astrakan process modeling method:

A Swedish graphical modeling method developed for enterprise description which can describe both activities and processes (Nilsson, 2004). It has fewer rules than IDEF0.

To model the activity model for factory planning it is important to understand these two methods, but all elements and rules of these two methods are not presented in this thesis due to the large content.

3.4 Using standards as architecture for the information backbone

To fulfill the vision of a sustainable information platform that can store, access, share, change and integrate information from different applications, information standards developed for this purpose are important.

According to the study, there is no information standard developed for representing factory layout and design information. Still there are several information standards that can be adapted to different domains in factory design. The factory design domain consists of the manufacturing system domain, building domain and media domain. This means that the standard can come from e.g. the mechanical domain, the building domain or the oil and gas domain. Unfortunately the research resources are limited. In this research three information models are selected for evaluation, if they meet the information requirement regarding factory layout design. These are Application Protocols 214, Application Protocols 225 and Industry Foundation Classes 2x4 from standards ISO 10303 and Industry Foundation Classes.

The common advantages of selecting and using these standards are:

- A standard and open way of representing information that everyone can take part of, i.e. a format that different applications can process if needed.
- A standardized information model that can be used as architecture for the information platform (with computer interpretable representation of information).
- A standardized terminology with definitions.
- A standardized modeling language to represent information models i.e. EXPRESS (ISO 10303-11).
- Standardized implementation methods e.g. XML representations of EXPRESS schema and data (ISO 10303-28).

In addition to the common advantages, there are also other reasons why these information models and standards are selected.

ISO 10303: Industrial automation systems and integration - Product data representation and exchange

ISO 10303 is also called STEP which stands for STandard for the Exchange of Product data. STEP consists of many parts, e.g. standardized modeling language, standardized implementation methods and information models for different application domains,

called Application Protocols (AP). Within STEP there are three types of information models, Integrated Resources (IRs), Application Interpreted Model (AIM) and Application Reference Model (ARM).

IRs are information models that can be used for more than one application domain and are independent of specific application domains. IRs are used as building blocks to develop domain specific AIMs which enable integration of APs within the STEP standard.

ARM and AIM are application protocol specific information models. ARM defines information types and their relationships within a specific domain, e.g. the building domain, tool domain and automobile design domain. AIM defines the data exchange schema for APs based on Integrated Resources (IRs), see Figure 19.

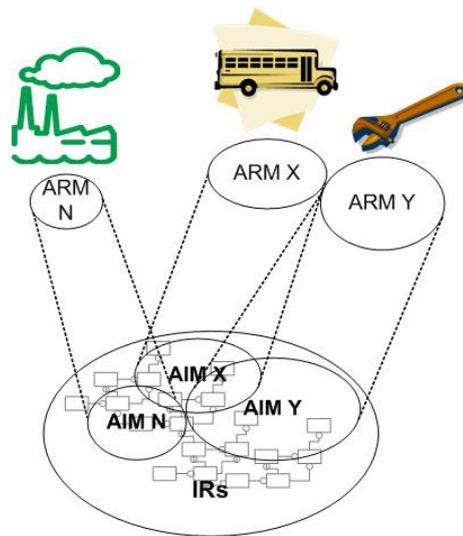


Figure 19 AIM's relationship to ARM and IRs

Figure 20 shows how ARM and AIM are mapped by an example "factory buildings name" for AP 214 and AP 225. The AP 214 attribute "Item.name" from ARM is mapped to the attribute "product.name" in AIM. The AP 225 attribute "Building.name" from ARM is also mapped to the attribute "product.name" in AIM. This is because the attribute "product.name" in AIMs comes from the same IR part (ISO 10303-41).

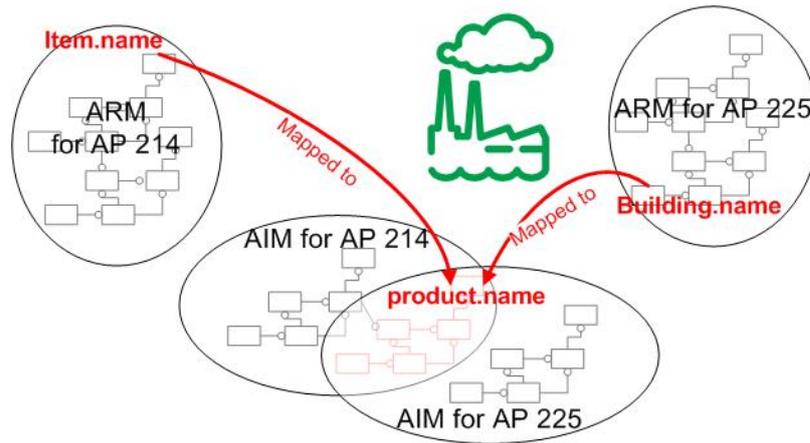


Figure 20 An illustration of how ARM is mapped to AIM, exemplified with attributes from AP 214 and AP 225

For this research, the possibility to integrate different domain information into an information platform is a desired functionality, this is because factory design consists of many expert domains that have their own applications that do their specialized work.

AP 214 and AP 225 are selected to be evaluated, and within this evaluation work, ARMs are used due to their domain specific information needs.

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 (ISO TC184/SC4, 2007), i.e. for mechanical products. It has been pointed out that AP 214 can be used to represent different aspects of a manufacturing system in development (Johansson, 2001), (Nielsen, 2003), (Mårtensson, 2006). AP 214 has also been used for the machine-tool kinematics implementation (Li, et al., 2011).

AP 214 is selected to be evaluated due to:

- Its generality.
- That it is possible to use an external reference data, such as a defined classification in ISO 13584 Part Library (PLIB), to represent the specific domain terminology. Nyqvist has used a part of AP 214 for the information structure and PLIB as a base for development of the cutting tool classification (Nyqvist, 2008).
- Its possibility to be integrated with other APs.

- Its possibility to represent a manufacturing system which is a part of factory design.

AP 225: Building elements using explicit shape representation

AP 225 is developed for the exchange of building elements and their shape, properties and spatial configuration information. 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 (ISO/TC 184/SC4, 1999). AP 225 is selected to be evaluated due to its focus on the buildings and their service systems, which is a part of the factory design, and it can be integrated with other APs if needed.

IFC 2x4 (RC1)

IFC (Industry Foundation Classes) is registered by ISO as ISO/PAS 16739 and is currently in the process of becoming an official international standard, ISO/IS 16739. IFC is developed to represent an information model structure for sharing construction and facility management data across various applications used in the building domain (Model Support Group, 2010).

Within the building domain the interest of integrating information during the building construction is growing fast, and the concept BIM is used frequently in this context. BIM stands for Building Information Modeling (sometimes for Building Information Model). It is the latest method to model and to handle building related information in the building construction industry. The content and definition of BIM can vary, but the main idea of BIM is to integrate the geometrical model with non-geometrical information for better communication between people and applications. BIM has been legally mandatory for publicly funded large construction work in Denmark since 2009 (Jensen, et al., 2011). More and more architects, engineers and constructors within the building industry are using the BIM concept to develop their building models. Unfortunately the BIM model developed by current applications within the building domain still is system dependent. IFC is developed to realize an open BIM vision and overcome the system dependency issue.

The IFC is selected to be evaluated due to:

- That it is focused on the buildings and their service systems.
- That it has more representation possibilities than AP 225 and contains more detailed information in the information model.
- Its possibility to integrate with a reference library, the International Framework for Dictionaries (IFD, ISO 12006-3). The IFD Library is

an open library, where concepts and terms are defined and semantically described (Bell, et al., 2008).

- That it is the latest effort from The International Alliance for Interoperability (IAI), receiving growing interest from users and organizations.

4 Result and discussion

The results in short:

1. A concept model for factory layout
2. A factory planning and realization pilot
3. An activity model for factory planning and realization
4. New formalizations for activity modeling
5. Principles for how to apply standards and concept models to factory design

Each of these results will be explained in their own sub chapter below.

4.1 Concept model for factory layout

A domain specific concept model is developed for factory layout, see Paper A and a upgraded version in appendix (A3).

This is in order to:

- Bring together the terms used in the domain by different domain experts, and how they are related.
- Identify the information that needs to be represented in factory layout applications.

The development of this concept model starts by asking the questions:

- What are the different views of factory layout?
- Does factory layout have different levels of detail?
- What kind of things can be included in factory layout?
- What kind of information is needed and what constrains the development of a factory layout?

The answers to these questions are:

- Different domain experts have different views (focus) and these views can be many, some of the examples are manufacturing system layout, safety layout and electrical system layout.
- Factory layout has different detailing levels such as block layout, conceptual layout and detail layout for the different development stages.
- The factory layout can include all the physical things at a certain detailing level.
- The information about the
 - Building with its walls, columns, floors, doors etc.

- Media systems. Electrical systems, process fluid systems, HVAC (heating, ventilation, and air conditioning) systems are all types of media systems.
- Manufacturing system with its robots, machine-tools, lift equipments, material handling systems etc.
- Connection ports for machines and systems.
- Geometry with its outer shape of the machines, systems etc.
- Laws, standards, directives and company specific regulations. These are types of constraints and requirements that need to be considered or followed during the factory layout design.
- Placement of equipment e.g. the machines.
- Properties related to e.g. machines and systems.
- Envelope area, as relating to both geometry and kinematics.
- Relationships between objects, properties, objects and properties as well as properties related to geometry.
- Organizational parts e.g. layout designer and project name.

More detailed information can be found in the concept model for factory layout in the appendix.

4.2 Factory planning and realization pilot

A pilot (a type of knowledge system) is developed for factory planning, design, realization and project follow up. This pilot is called the factory planning and realization pilot. Due to the massive content and license issues, the information within the factory planning and realization pilot is not available in this thesis. The pilot is available at:

www.produktionslotsen.se (DMMS, 2009)

This pilot is developed in order to:

- Ease the knowledge and information sharing and reuse, in factory planning, design, realization and follow up.
- Ease the collaboration and semantic interpretation between experts from different domains which are involved in factory planning projects.
- Give support to people who are working in factory planning, design and realization, as many books and applications do in this area. Works as a reference process model for the domain. The main difference between this pilot and the books, e.g. "Facilities Design" (Heragu, 2006) and "Factory Planning Manual" (Schenk, et al., 2010) is in making relations between activities and information content explicit.

The development of this pilot started by asking the following questions:

- What are the activities involved in factory planning and design?
- What information is needed about the activities involved in factory planning and design, i.e. information about what-to-achieve, how-to-achieve and why-to-achieve?
- How should the information and knowledge be represented and presented in this pilot (the same representation can be presented in different ways and vice versa)?

The answers to these questions are:

- The activities in the factory planning and design are presented in the activity model in the fold-out. The main modules of these activities are shown in Figure 22.
- The information needed for the activities can partially be found in the activity model.
 - What-to-achieve information is described as outcomes of each activity. Detailed what-to-achieve information can be found in outcomes of the pilot.
 - How-to-achieve is described as activity name and within each activity as “purpose”, “description” and “tips”. Figure 21 is an example of an activity from the factory planning and realization pilot. To support “how-to-achieve” templates, examples and best practice are also included in activities.
 - Why-to-achieve is described as a part of controls in each activity in the pilot, specific standards and laws are connected to the specific activity as controls.
- The information and knowledge are represented by the activity model with its ICOMS. Details about how the information is represented are described in Chap. 4.3, theories and methods are described in paper D. How the information and knowledge is presented can be seen in the pilot, Figure 18 is a small example.

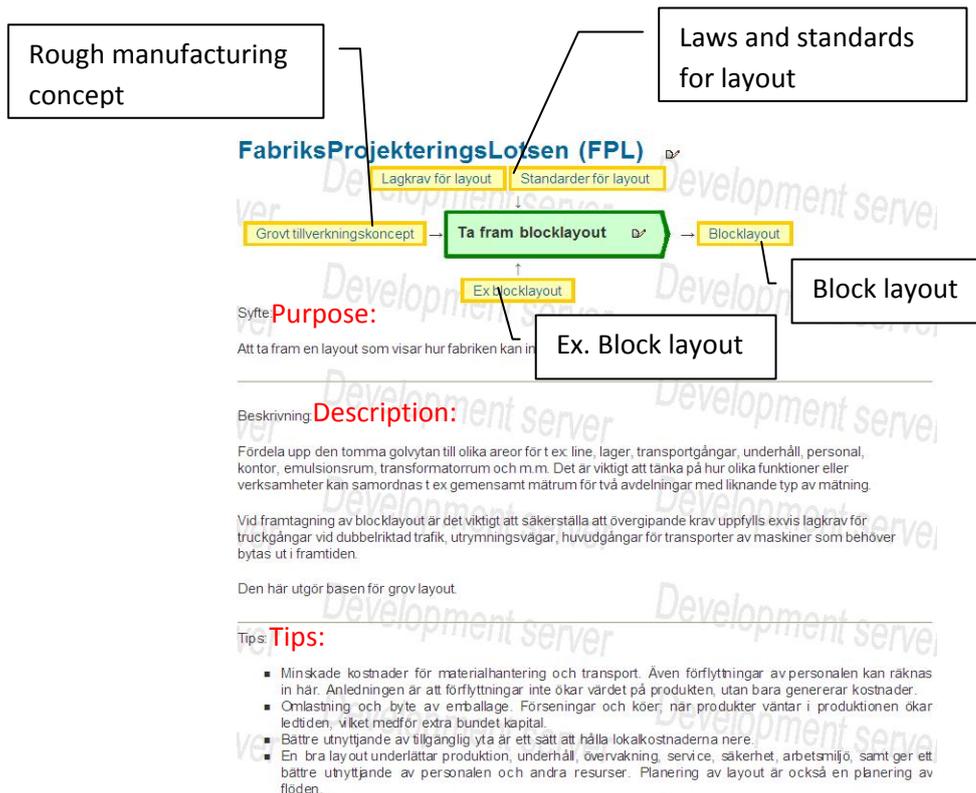


Figure 21 Activity: Formulate block layout – screenshot, translated in English below

Activity: Formulate block layout

Purpose:

To develop a layout that shows how the factory can be divided into spaces.

Description:

Dividing the empty floor into different spaces, e.g. manufacturing system line area, warehouse, transport path, maintenance area, personnel area, office, emulsion room etc. It is important to think about how different functions or activities can be coordinated e.g. common measuring room for two departments with similar types of measuring.

When developing a block layout it is important to make sure that the general requirements are accomplished, e.g. legislative requirements

for forklift path for two-way traffic, emergency exits, and main path for transportation of machines which may have to be changed in the future.

The block layout forms the base for the rough layout.

Tips:

- Reduced costs for material handling and transports. Relocation of personnel can be considered here. The reason is that reallocations are not value-adding for the product, they only add costs.
- Reloading, packaging, delays, queues and products waiting in the production will increase the lead-time, which results in increased fixed capital.
- Better use of available areas is a way to keep the building rent down.
- A good layout facilitates production, maintenance, surveillance, service, security, working environment, as well as a better utilization of personnel and resources. Planning of layout is also a planning of the flow.

The factory planning and realization pilot is based on the activity model illustrated in the fold-out. The pilot is divided into six modules and most of them have a number of activities. The six modules are activity based, as well as project based, which gives the reader a better overview of the whole process, see Figure 22 and Figure 23.



Figure 22 Factory planning and realization modules - Screenshot, translated into English below

The six modules are briefly described below.

Module 1 - Assess project potential - Initiate project:

Investigate the feasibility of the factory planning project within the time and cost limitations.

Module 2 - Formulate the project definition - Pre-project:

Put together requirements and information for the planned project and form the basis for the project decisions and feasibility.

Module 3 - Structure and define the production requirement - Detail project:

Break down the overall requirements to the specific requirements for the subsystems and equipment.

Module 4 - Design the system - Detail project:

Detail, verify and integrate the models of the building parts, media systems and equipment to form a whole, realizable system model.

Module 5 - Realize the system - Realize the project:

Co-ordinate the installation works for the building parts, media systems and equipment, and install the system.

Module 6 - Hand over and follow up - Follow up the project:

Hand over the project result (e.g. a factory ready to produce), with its documentation, to production.

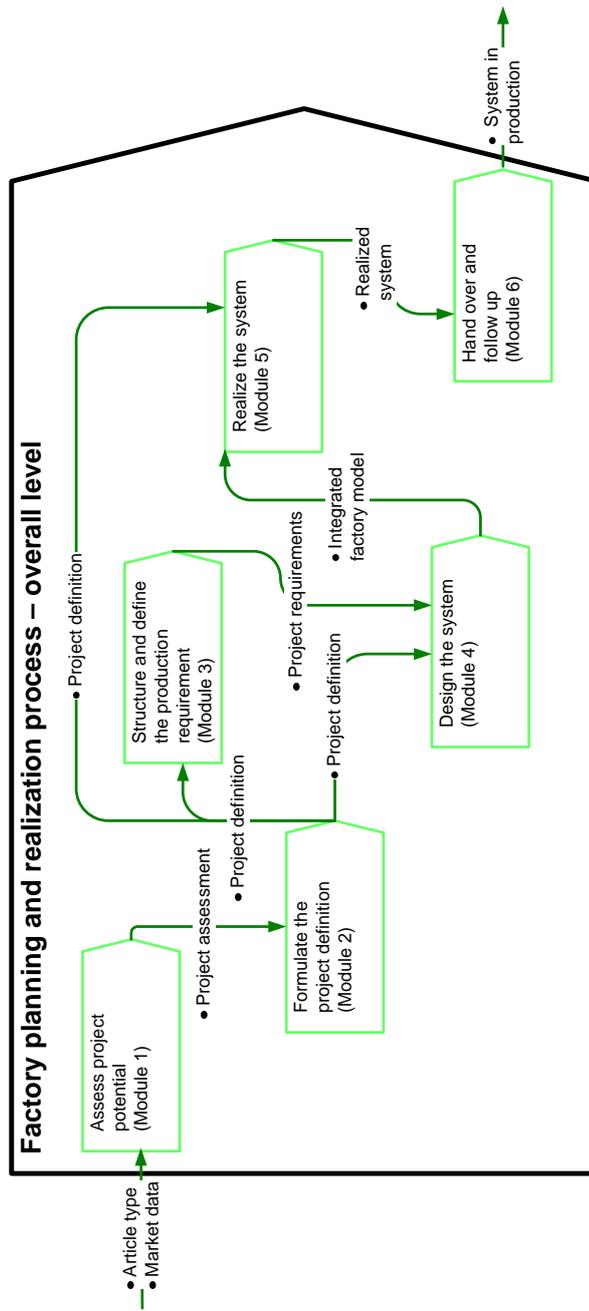


Figure 23 Factory planning and realization process - overall level

The advantages and limitations of the factory planning and realization pilot

The advantages of the pilot are many, and include:

- Supports different factory planning scenarios, at large and in detail.
- Shows activity relationships as well as information relationships.
- Give support from the beginning to the end for better decisions.
- Provides a source of knowledge for industrial employees and educational material for both industries and universities in the area of production.
- Is a platform for future research.

There are some limitations to the pilot due to various reasons, such as:

- The standards and laws within the activities are best suited for factories in Sweden, because the Swedish laws and standards are used.
- The best practices are collected from only a few companies.

4.3 The activity model and the modeling principle

The factory planning and realization process in a detailed activity model (fold-out) is developed and attached at the end of this thesis.

Below are some explanations about the modeling principle (elements and rules) used to model this process.

The modeling principle:

In the fold-out an activity model of the factory planning and realization is presented. This activity model is modeled based on Astrakan notation and the IDEF0 modeling method, with three new formalizations (rules), due to the need to represent the process in as clear and simple way as possible for the reader to understand. The three most important criteria in forming new formalizations for this process are:

- Minimize as many arrows as possible, for a clean picture of the process without losing any semantics.
- Have the whole activity model in one diagram, for a better overview and in order to follow with greater ease through a series of activities.
- The output is used as a trigger and requirement for the next activity/module.

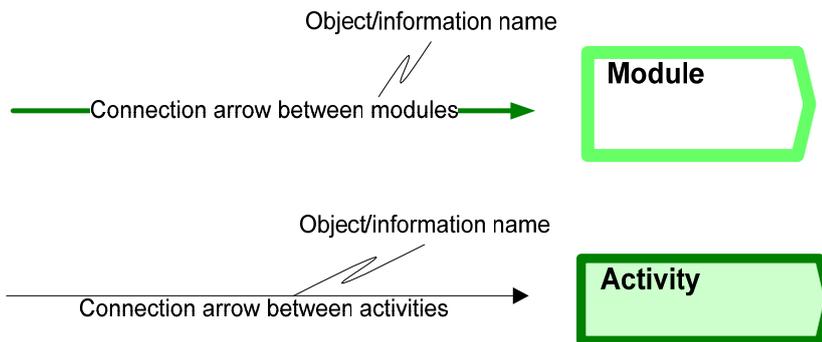
The reading guidance with new formalizations is presented in Figure 24 to Figure 28.

With these three new formalizations, the model is simplified for the reader but the details and semantics in the activity model are retained. It is easy for the reader to follow the activities without having any deeper knowledge about the modeling method, when the whole model can be presented in the same diagram and the arrows are minimized in a logical way.

The studied modeling methods do have the ability to present the activities in the factory planning and realization process, but then the model gets very complicated and that makes the process difficult to overview.

The activities are modeled in sequence, in line with IDEF0. This does not mean that the work is done in such a time sequence.

Reading guidance



Some of the objects/information have been gathered under one general name for simplicity. The idea is to manage corresponding objects/information in the yellow and blue lines in a database to support the activities.

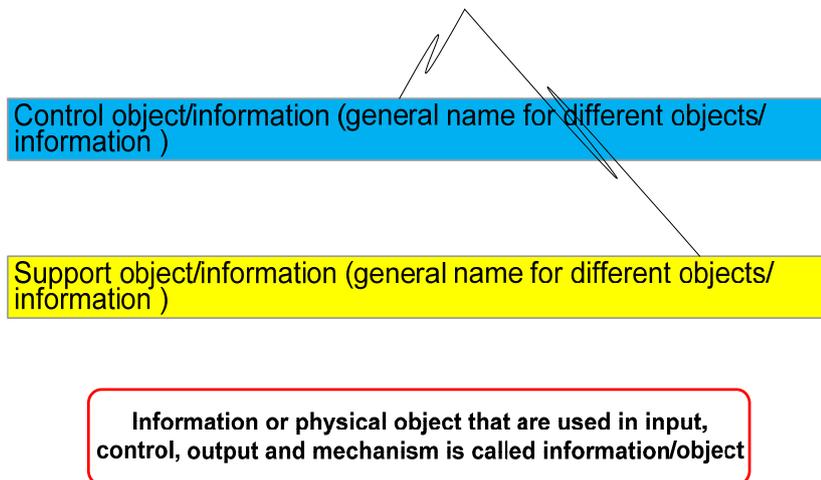


Figure 24 Reading guidance 1

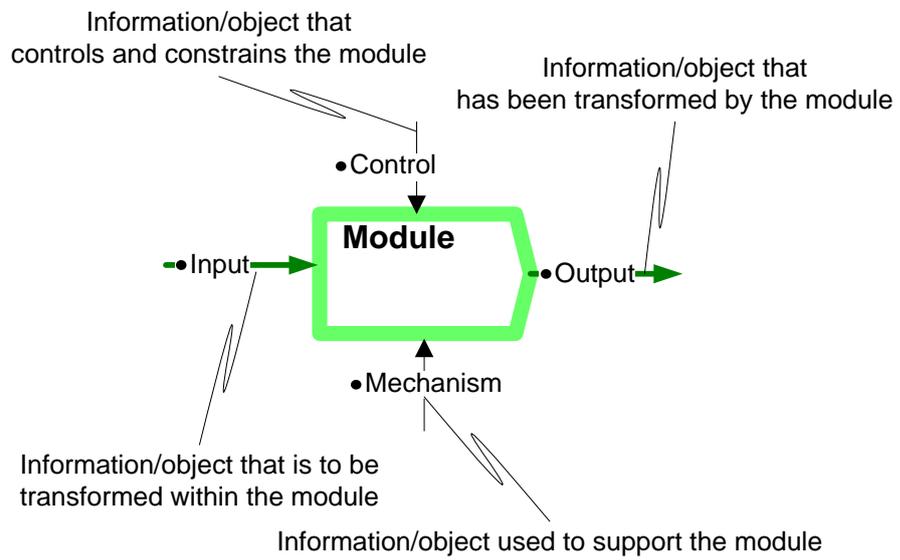
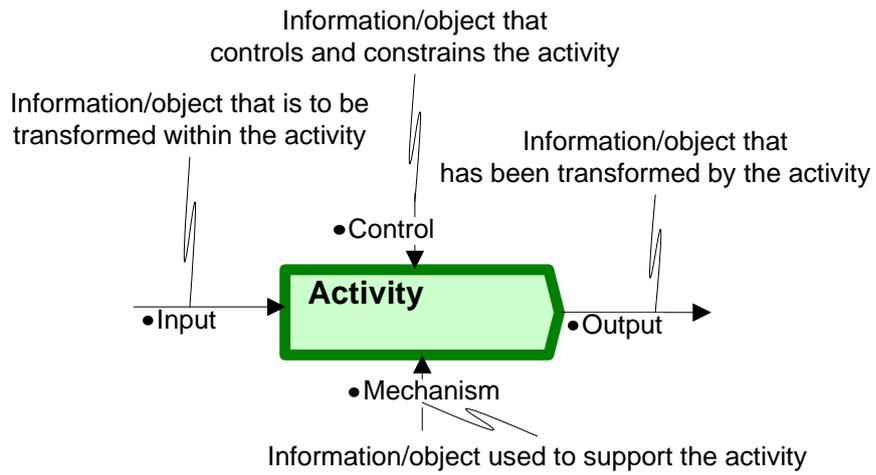


Figure 25 Reading guidance 2

Formalization 1 - Difference between the modules and the grouped-activities

Grouped-activities are created as within IDEF0, with one narrow arrow representing all output from the final activity within the group.

A module is created to define an important project phase, after which a decision will be made for project continuation. A module can contain many single activities and grouped-activities.

The output from a module is a collection of the important results generated within the module and processed to a final output, on which a decision will be taken. Here it is important to define the key information for further work. It is drawn as a thick arrow.

The different designs are created to highlight and differentiate this.

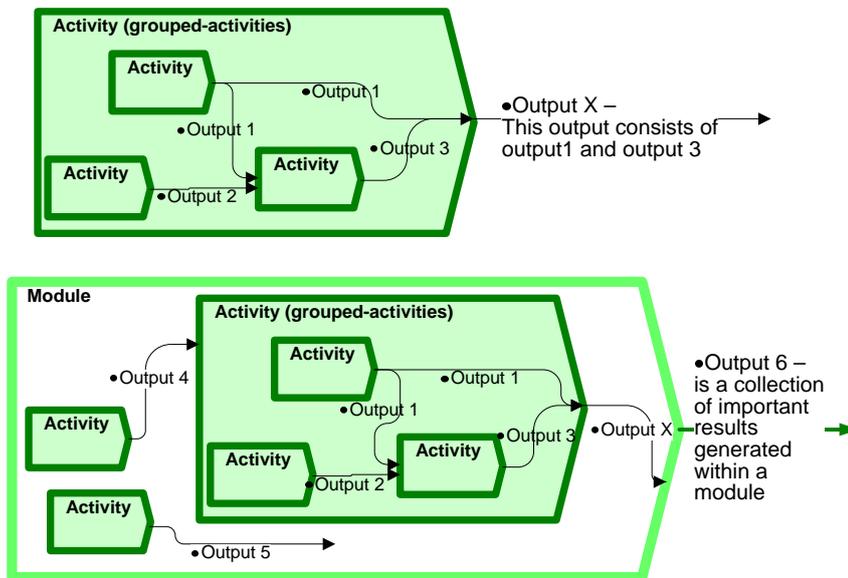


Figure 26 Reading guidance 3

Formalization 2 – Each bullet is an information/object:
A bullet in an arrow is an information/object, this means every bullet is an arrow.

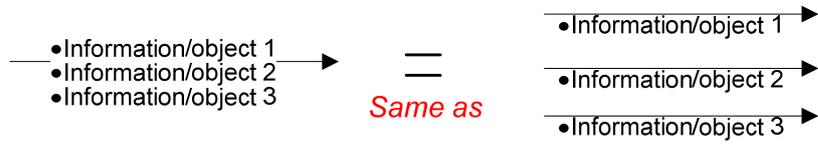
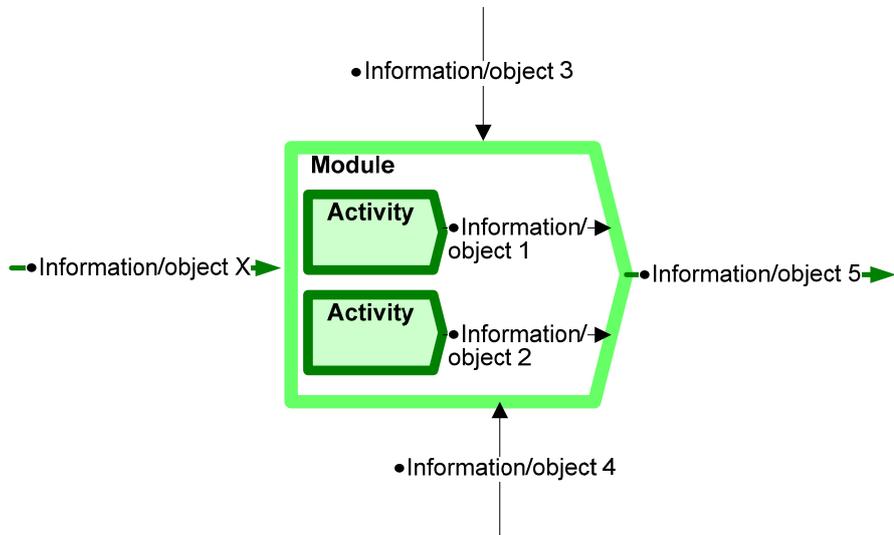


Figure 27 Reading guidance 4

Formalization 3 - Inheritance

All the arrows into (pointing) at an activity or module are also inherited by all lower level activities, i.e. the arrow doesn't have to be connected to the activities within grouped-activities.



== *Same as*

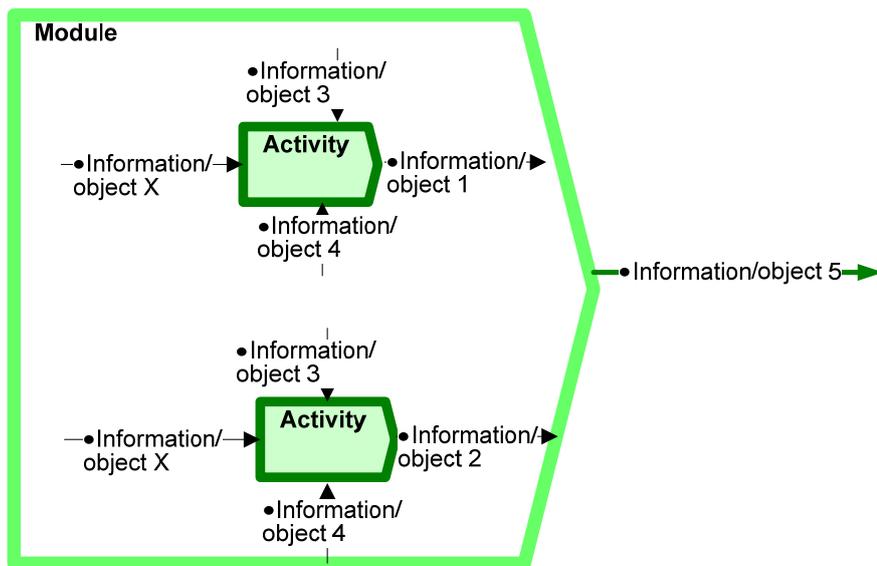


Figure 28 Reading guidance 5

The differences between existing modeling methods and the new formalizations:

The main differences between the new formalizations and the modeling methods IDEF0 and Astrakan are in the three formalizations, presented in the reading guidance. The differences are compared below.

Formalization 1 – difference between the module and the grouped-activity

- In the factory planning and realization process, modules exist due to the project perspective and another arrow design is used to distinguish the module result. Many activity results are “consumed” in the module and therefore the output is not a summation of the results from activities within the module, while the outputs from grouped-activities contain all output from the final activities within a group.
- In IDEF0, it is one design.
- In Astrakan different types of arrow and box design are used but the meanings are not clearly defined.

Formalization 2 – each bullet is an information/object

Neither IDEF0 nor Astrakan has the ability to use a bullet as an information-object.

Formalization 3 – Inheritance

Neither IDEF0 nor Astrakan has this kind of inheritance defined.

4.4 Principles for how to apply standards and concept models to factory design

In factory design the main focus is on developing a factory layout that can be realized. For this, different information (such as information in the concept model for factory layout) from different domain applications needs to be integrated. It is impossible for all information to be developed within one application. The experts are using the applications that are most suited for their job, e.g.

- Electrical system design applications to design the electrical systems.
- Building design applications to design the buildings.

Figure 29 is an illustration of it. For the factory layout design, only a part of the information developed by different applications is needed to be integrated.

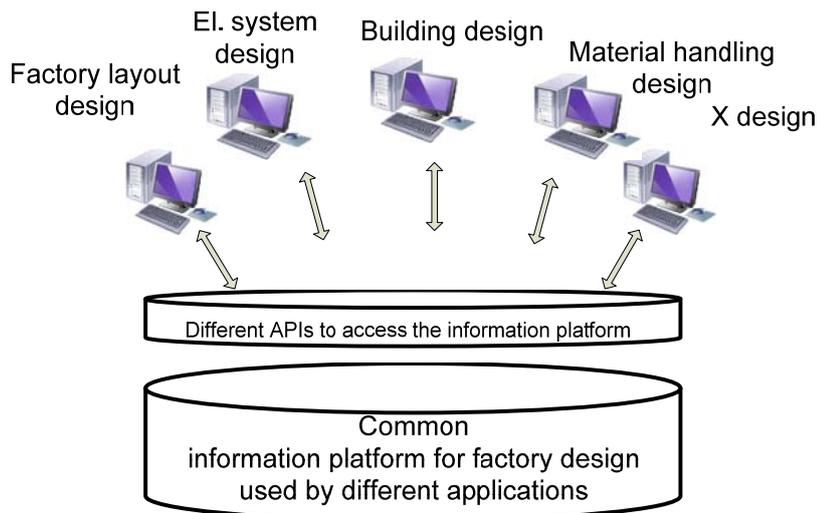


Figure 29 A common information platform for factory design to support different applications

For this, existing information models from STEP AP 214, STEP AP 225 and IFC 2x4 that are not delimited to factory design have been selected to be evaluated. The evaluation is based on the information that answers the first research question in Chap. 4.1.

According to the evaluation none of these three information models can be applied for use directly. The information models within IFC and AP 225 don't have abilities to represent manufacturing systems as they are. These information models are developed for the building domain, with media systems that support the buildings. The terminologies, information types and their relationships within these information models are very domain specific and the manufacturing system is not a part of these.

Some of the main object types that are defined in IFC are:

- Building elements, e.g. walls, beams and doors.
- Distribution elements, e.g. heating systems and plumbing systems.
- Transport elements, e.g. escalators and elevators.

Main object types of AP 225 are:

- Structure enclosure elements, e.g. walls, beams and floors.
- Service elements, e.g. plumbing systems and electrical systems.
- Fixture equipment elements, e.g. doors, furniture and windows.

IFC and AP 225 are both for the building domain with its media systems, but IFC can represent more information and contain more information types and relationship types as compared to AP 225.

The information model within AP 214 is generic as compared to IFC and AP 225. In AP 214 the information types are not predefined and use the classification method to classify the objects and properties. This means AP 214 can be used to represent factory layout information, if the information model is enriched with factory design domain specific concepts. There are two ways of doing this:

- By referring to an external library (external classification).
- By writing each domain specific term as an entity and a property name.

The last option is not a desirable solution because the flexibility of the information model will be limited (similar to IFC and AP 225). For the first option a classification work needs to be done. There are different ways to develop a classification. A domain specific concept model will be the base for this work, as mentioned before.

In factory design, it does not have to be one classification, it should preferably be several classifications; one for each expert domain such as for building design, electrical design and manufacturing system design. However the details of the evaluation can be found in Paper E and below are the general principles about how to apply ISO 10303 and the concept model to the factory design domain.

The proposal is to use information models from ISO 10303 as the architecture of the information platform for factory design, see Figure 30. In factory design information from different applications need to be integrated. ISO 10303 contains different application protocols for different domains and these can be integrated, see Chap 3.4.

It has been stated earlier that the factory layout is the core result of the factory design. For this, AP 214 is suggested as a starting point, i.e. using AP 214 to represent information related to factory layout.

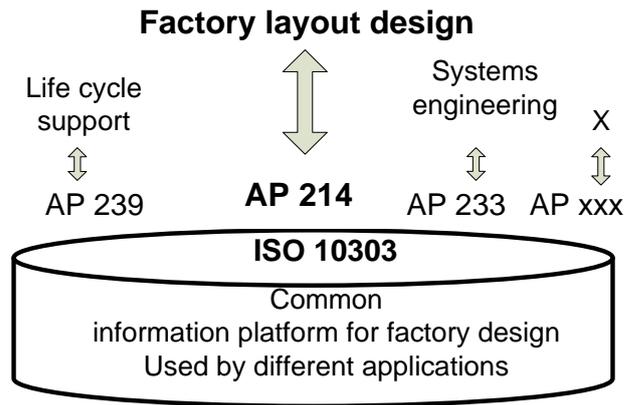


Figure 30 Use ISO 10303 information models as information architecture for the common information platform

The common information platform for factory design can then be extended by other APs to take care of detail information of other such as:

- Building design - how the building elements are related and structured, the materials and the needed processes.
- Requirement management - how requirements are structured and related, where they come from and if they are fulfilled.
- Life cycle support - how the physical factory with its machine-tools, robots etc. changes from its original state during the use phase for a better factory redesign.

One way to minimize the classification work in AP 214 is to use the concepts (described in entities and properties) in the IFC information model as a classification for the building and media domains.

One example is the concept "space" from the concept model for factory layout. The IFC entity "IfcSpace" is used to classify and define the entity "Item" in AP 214. Different ways can be selected to classify entities and properties in AP 214, Figure 31 shows one way to represent it. One disadvantage with concepts from IFC entities is that these always start with "Ifc".

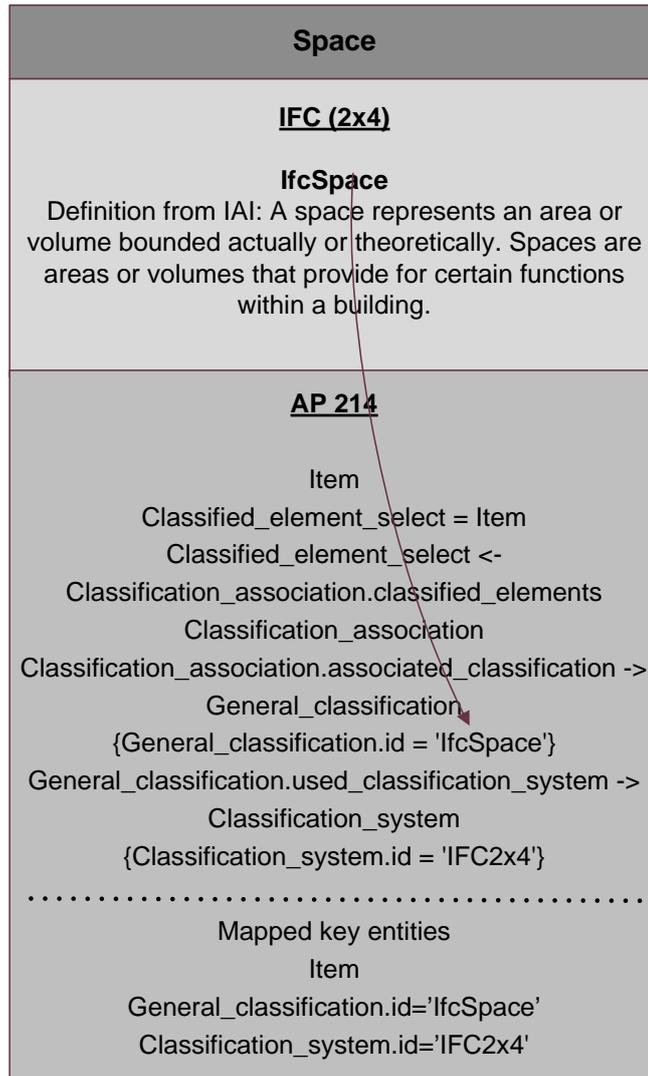


Figure 31 Using IFC as domain specific classification to enrich AP 214

The common information platform can then be linked to the factory planning and realization pilot by the domain specific concept model. A concept model for factory layout is developed as the first step, see Figure 32 for a description. More details are described in Paper F. With the concept model connected to the pilot, the semantics are captured by the activities with descriptions related to the concepts.

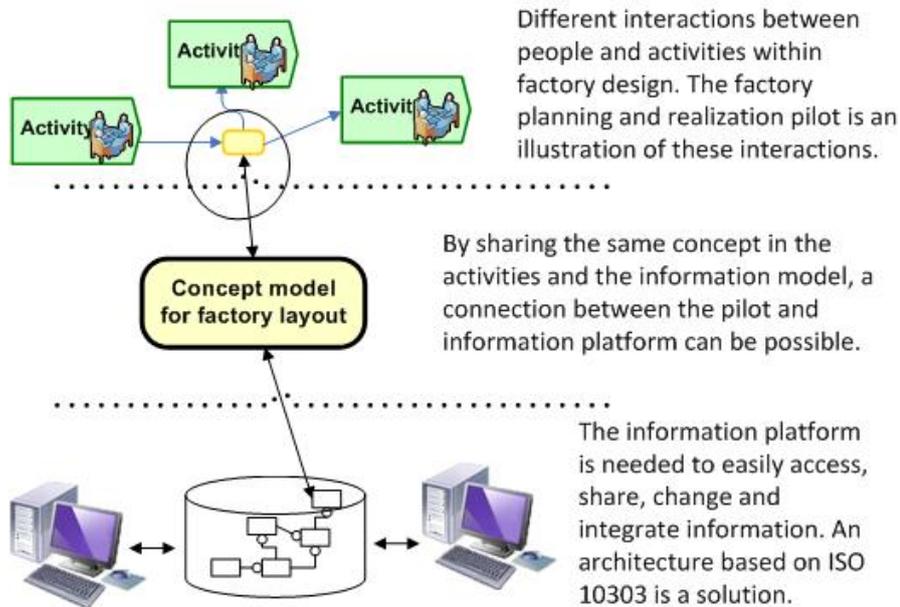


Figure 32 The concept model as the link between pilot and information platform

In Figure 33 an example is illustrated with the concept “space” from the concept model. The concept “space” is defined and classified based on IFC, and used to link the pilot and the information model.

In factory layout, development of the first stage of the factory layout is a block layout. In the block layout the space for different areas is determined, such as areas for buffers and machine groups, i.e. space division is a result from the activity: formulate block layout.

The concept “space” needs to be defined and classified in factory design. This can be done e.g. by using IFC as a domain specific classification for the building and media system, see Figure 31 for the definition.

By defining the attribute "application_domain" as factory layout (i.e. the application domain is factory layout domain) and classifying the entity "item" in the AP 214 information model with "space" from IFC, the entity "item" is specified for layout design.

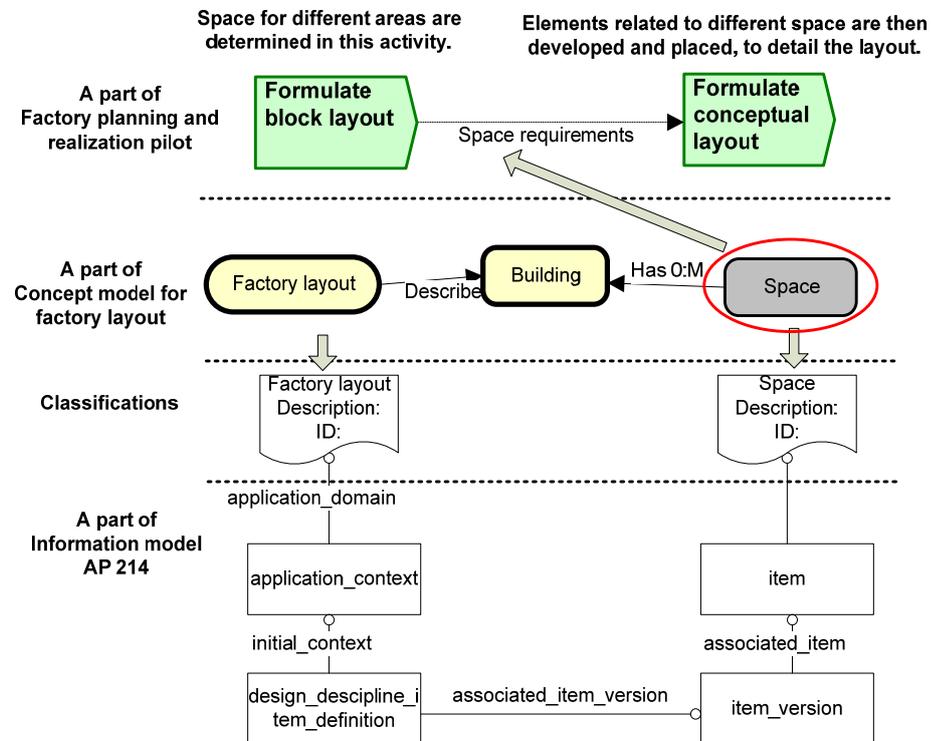


Figure 33 An illustration of how the concept "space" is related to the pilot, classification, and information model

Figure 34 illustrates one way in which the concepts of a concept model for factory layout can be used in future factory layout design applications. In the Figure 34 the same concepts are used as those in the concept model and the machine model, the matching parts are numbered with the same number.

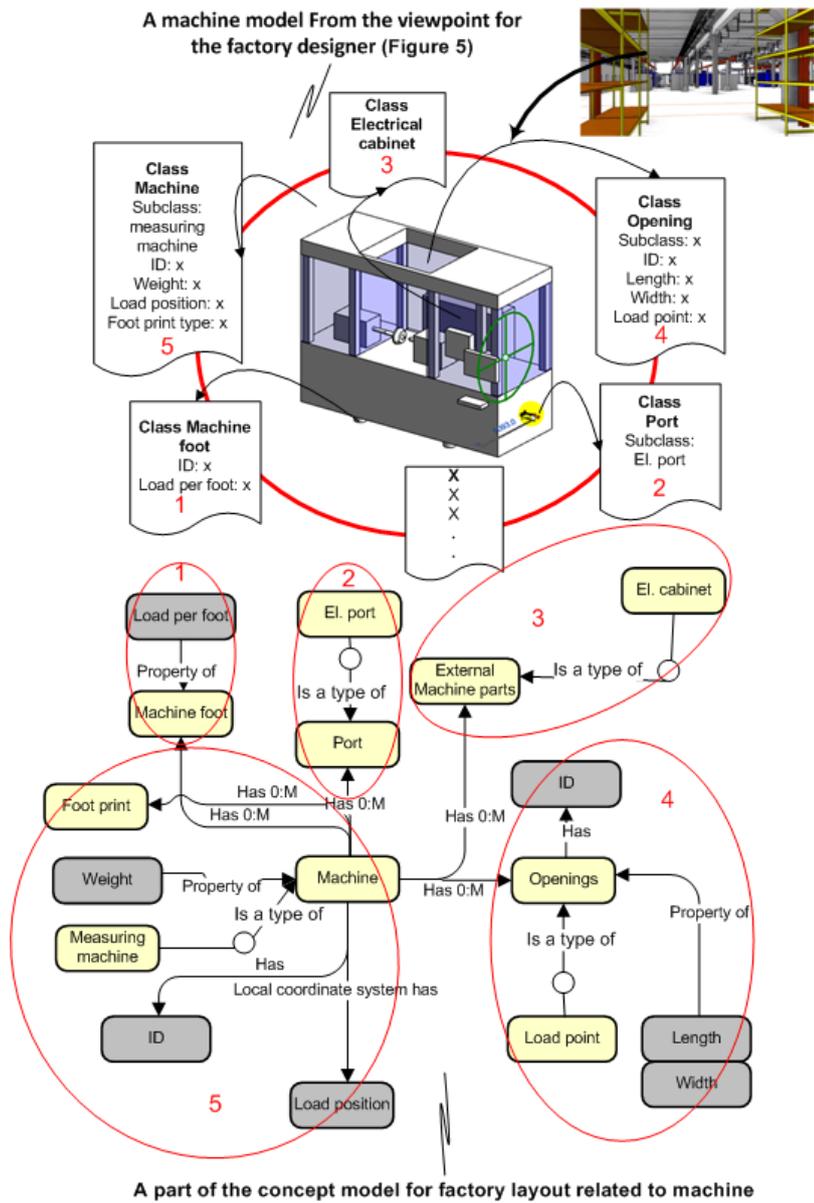


Figure 34 The same concepts used in the concept model and the factory layout design application

4.5 Answers to the research questions

This sub chapter provides short answers to the research questions. The detailed answers are in Chap. 4.1 to Chap. 4.4.

Question 1: What information ought to be represented in a factory design model – in an information platform for factory design?

Answer: Information about

- Block layout, conceptual layout etc. that should be generated from the layout model, i.e. detailing levels of the factory layout.
- Building with its walls, columns, floors, doors etc.
- Media systems. Electrical systems, process fluid systems, HVAC (heating, ventilation, and air conditioning) systems are all types of media systems.
- Manufacturing system with its robots, machine-tools, lift equipments, material handling systems etc.
- Connection ports for machines and systems.
- Geometry with its outer shape of the machines, systems etc.
- Laws, standards, directives and company specific regulations. These are types of constraints and requirements that need to be considered or followed during the factory design.
- Location of e.g. buildings, machines and systems.
- Properties related to e.g. machines and systems, which are important during the factory design.
- Envelope area - the areas which are dangerous to visit or with existing clash possibilities.
- Relationships between objects, properties, objects and properties as well as properties related to geometry.
- Organizational parts that is related to factory design.

More detailed information can be found in the concept model for factory layout in the appendix.

Question 2: How can the information in the platform be created and made available in different applications?

Answer: This can be made possible by using ISO 10303 that fulfils the criteria for a sustainable information system, described in Chap. 3.4. AP 214 is suggested as a starting point, i.e. using AP 214 to represent information related to factory layout in this platform.

Question 3: What are the activities involved in factory planning and design?

Answer: This answer can be found in the activity model for factory planning and realization. All activities in the fold-out are about factory planning and design, besides activities about installation in the realization module.

Question 4: What information is needed about the activities in factory planning and design, i.e. information about what-to-achieve, how-to-achieve and why-to-achieve?

Answer: This answer can partially be found in the activity model. What-to-achieve information is described as outcomes in each activity. How-to-achieve is described as the activity name. Why-to-achieve is described as a part of the controls in each activity, but the detailed answers are described in the factory planning and realization pilot, with a detailed description of each activity.

Question 5: What are the important common concepts and applied terms in factory planning and design?

Answers: This can be found in the concept model for factory layout and as ICOMs in the activity model for factory planning and realization.

Question 6: How can the concepts be utilized to realize the integration?

Answer: This can be realized by developing a domain classification based on the domain specific concepts model, such as the work done by Nyqvist on cutting-tools. In the classification, every concept is described and has a unique identifier. The concepts in the classification are then used by the information model from the selected standards and the factory planning and realization pilot. A part of Chap. 4.4 describes the principle of how to apply standard information models and concept models to realize the integration.

The scientific results:

- By capturing the specific knowledge and information in a concept model, activity model and pilot for the factory planning and design domain, which does not yet exist in today's systems and models.

- By Pointing out a solution for better information management for factory design, i.e. principles for how to apply standards and concept models to factory design.

4.6 Discussion

Discussion about the data and information collection to research:

There are different methods to collect the data and information from people e.g. by interviews and by questionnaires. In this research interview method is chosen due to the complexity and broadness of the research subject. Questions in a questionnaire need to be simple and easy to answer by the person, which is not possible in this situation.

Discussion about the research questions and the answers:

The research questions are formed based on the objectives, which are formed based on visions. This means that the research questions cover a range of questions due to the big picture presented in the vision. The results accomplished in this research don't cover all the details that need to be answered, only a part of them which is the most important part in this research and for the future research.

5.1 Conclusion

This research provides a holistic view of factory planning and design with its current situation and vision. There are three main results that need to conclude this research:

- A factory planning and realization pilot (a type of knowledge system) with what-to-achieve, how-to-achieve and why-to-achieve information based on interviews and state-of-the-art study.
- A proposed architecture for factory design information platform based on state-of-the-art studies and issues, needs and hopes that experts have expressed.
- A concept model for factory layout for a common understanding, which works as an information requirement specification in the domain based on the interviews and state-of-the-art studies.

These three parts form a holistic information driven scenario for the future, i.e. how different information should be managed for best use and reuse in the factory planning and design domain, to best support the human work and knowledge-based engineering.

Below describes how the problems are addressed.

Problem one: What-to-do and how-to-do information for factory planning is scattered.

This situation is improved by the factory planning and realization pilot.

Problem two: Information about resources within a factory, needed for the development of factory design, is scattered or missing.

This situation is improved by the concept model for factory layout and activity model for factory planning and design. The principles of how to apply standards for factory design addresses also this problem. This is a necessary step to take before the problem can be solved.

Problem three: Geometrical models of machines and buildings are saved in different application formats.

The problem is addressed by developed principles for how to apply standards for factory design. This is a necessary step to take before the problem can be solved.

5.2 Applicability of the work

In general this thesis works as a specification:

- For future development of a common information platform for factory design. The main results in this thesis are important core parts in such development. Core part number one, is the principles for how to apply standards and concept models. Core part number two, is the concept model for factory layout.
- For the manufacturing industry as a guideline for the future working methodology based on the vision. The factory planning and realization pilot works as a reference process model with guidelines for people working in factory planning and design.

5.3 Future work

There is a lot of work that needs to be done before the vision is accomplished and the problems solved. Some examples of this work are:

- Continuation of the development of concept model for factory design, in same direction as concept model for factory layout.
- Continuation of the development of reference process model to identify the common activities between the different expert areas related to factory planning and design.
- Test of how the concepts (terms and definitions) from IFC can be best extracted and used by AP 214. There are several ways to carry out this, such as creating a factory design classification by mapping IFC terms and definitions.
- Test and verify implementation strategy for computer interpretable domain specific classifications based on concepts. The classifications can be in OWL format or according to PLIB.
- Test implements of the proposed approach of the common information platform starting with AP 214.
- Test adapts domain applications to work with the information platform.

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Paper A

A Concept Model for Factory Layout Design

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Paper B

The Digital Factory and Digital Manufacturing - A Review and Discussion

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Paper C

Software Tools for the Digital Factory - An Evaluation and Discussion

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Paper D

Production Pilot for Co-operation in Factory Development

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Paper E

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

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Paper F

**An Information Communication Approach for Factory Layout
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APPENDED CONCEPT MODEL

**Concept model for factory layout -
a non-exhaustive model**

APPENDED PROCESS MODEL (fold-out)

**Factory planning and realization process -
detail level**

