PSS-CAD: An Approach to the Integrated Product and Service Development

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Abstract

IPS² consist of interacting product and service elements, which need to be developed simultaneously and jointly under permanent consideration of their interdependencies. The increased complexity of the integrated, multi-domain development requires methods and tools to support the IPS² developer. The presented methodical approach is based on modelling and visualizing the interdependencies between the IPS² elements. The PSS-CAD support system provides the authoring tool for creating, visualizing and maintaining this model during the integrated IPS² drafting stage. As a software module within the IPS² assistance system, the PSS-CAD support system completes the IT support tool-chain for the entire IPS² planning and development process.

Keywords:

Industrial Product-Service Systems, Integrated product and service development, PSS-CAD, Product-service module, IPS² assistance system, IT-based development support, Drafting stage

1 INTRODUCTION

The importance of pure selling of a technical product decreases with the growing relevance of long-term customer-supplier relationships. A new understanding of a product offer puts the focus on the value being provided. Industrial Product-Service Systems (IPS²) consist of integrated, interacting product and service elements and create an additional benefit throughout their life cycle for customers and suppliers in the context of industrial applications.

During planning and development of IPS², the various interdependencies between the product and service elements have to be considered. The drafting and design stage is the most detailed level of the development. Here, the elements of different domains are defined, coordinated, tailored and integrated into product-service modules (PSM), which form the building blocks for IPS².

This paper presents a methodical approach to the integrated product and service development during the drafting and design stage, as well as a concept for the implementation in an IT-based development support tool.

2 LIFE CYCLE OF INDUSTRIAL PRODUCT-SERVICE SYSTEMS

Industrial Product-Service Systems represent customized solutions and allow a flexible adaptation to changing requirements of both customers and suppliers by the resulting solution space [1]. The extension of the solution space increases the organizational complexity, because the time dimension of the service elements contained in the Industrial Product-Service Systems sets special requirements for tools and methods of the IPS² provider [2]. With the strong consideration of customer needs and the inevitable extension of the focus on the operating phase by the IPS² provider, it is no longer sufficient to focus on planning and development only.

Therefore, the entire life cycle from planning to resolution needs to be considered for an IPS² [3]. Two main areas can be distinguished: The creation of IPS² and the operation of IPS². They consist of the phases:

- IPS² planning,
- IPS² development,
- IPS² implementation,
- IPS² operation, which consists of the provision of IPS² service elements and the use of the IPS² product elements and
- IPS² resolution.

At the beginning of the IPS² planning the contact with the customer is being established through the IPS² provider. From the identified customer needs and accompanying boundary conditions, the IPS² provider derives the IPS²-specific requirements, while the requirements of the IPS² provider are also incorporated [1]. These requirements are not yet solution-based, but rather describe the required functionality of the Industrial Product-Service System. Once the requirements are established, a contract can be concluded with the customer on this basis. For the contractual arrangement, the fundamental scope of the Industrial Product-Service System must be in place.

During IPS² development, the requirement descriptions are used in the first step to develop a functional and a conceptual model, respectively [4]. The refinement of the concepts during the drafting and design phase creates the necessary product and service elements of the Industrial Product-Service System. Preferably, they are modularised in product-service modules, which form the entire IPS² that is summarized in an IPS² product model.

During the IPS² implementation the required product elements are manufactured. The needed resources for the service elements, for example, are also established in this phase. The ramp-up completes this life cycle phase.

During the IPS² operation the IPS² product elements are being used and the IPS² service elements are being provided. The IPS² resolution is performed according to the contractual agreement, whether and which elements can be reused and how the remaining IPS² elements can be abandoned.

3 IPS² ASSISTANCE SYSTEM

The IPS² developer has to combine and use data from many different expert domains, find individual solutions for the customer and interact with the customer in order to obtain the best customized solution. It can be summarized that IPS² development involves higher requirements contrary to conventional product design or service engineering [2].

While IT support for product design has been available for decades, IT tools for service engineering still have a relatively young history, and the integrated development has emerged in the conceptual design area [4][5][6]. The IT based IPS² assistance system [7], developed at the Institute for Machine Tools and Factory Management, supports the entire integrated planning and development process of Industrial Product-Service Systems. This software system guides and supports the developer along the concurrent development processes of products and pertinent services while constantly considering their mutual interrelations starting at the earliest development phase. In order to reduce the complexity of the development task, the developer is provided with product-service module libraries and technology databases in which aggregated knowledge about products, services and processes and pre-developed module solutions are stored.

Figure 1 depicts the software architecture of the IPS² assistance system. It has a modular structure and serves as a framework for the integration of software modules and partial data models that correspond to the respective process steps. So far the following software modules have been implemented: identification of customer and provider needs and their transformation into requirements, the IPS² configuration module together with the product-service module library and compatibility information database. A top-down approach has been applied to the task, so that after examining the creation of IPS² from pre-developed product-service modules, the research is now focusing in more detail on the creation of the product-service modules, consisting of product and service elements, and the detailed interdependencies between these elements. The IT support that is being developed will integrate into the IPS² assistance system as a software module to support the developer during the drafting stage.

4 ELEMENTS OF INDUSTRIAL PRODUCT-SERVICE SYSTEMS

Industrial Product-Service Systems aim to provide value to the customer through an integrated solution. For this purpose the needs and requirements are met by alternative combinations of product and service elements. In order to examine the interdependencies between the elements, the subject matter needs to be looked at.

4.1 IPS² product elements

The product elements of IPS² are viewed from an engineering perspective and thus represent the saleable and usable result of the development and manufacturing process as a technical part or system. They are artificially created, have geometrical and material properties and fulfil a function [8]. In today's information age, the share of non-mechanical elements in innovative technical products is constantly increasing. Therefore, IPS² product elements can be subdivided into the disciplines mechanics, precision mechanics, fluid technology, electrics and electronics as well as software and automation technology [9].

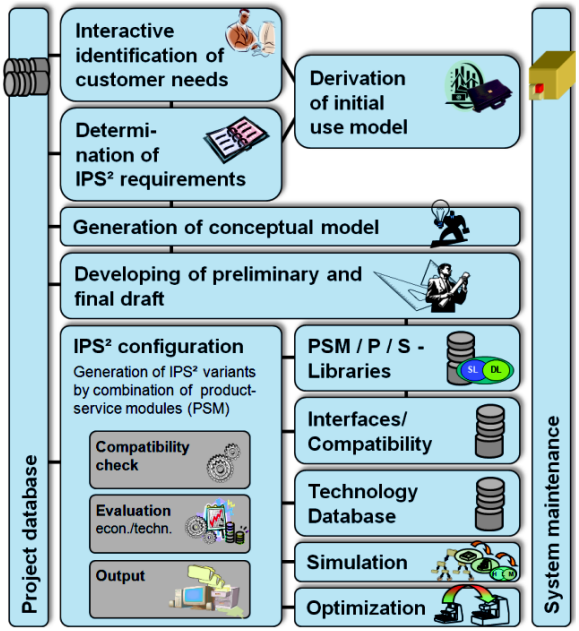

Figure 1: Modular software architecture of the IPS² assistance system [2].

4.2 IPS² service elements

The term "service" can be defined with various approaches: Enumerative, institutional, negative and constitutive [10]. The constitutive definition is a well established approach. It characterizes this term through the potential dimension, process dimension and result dimension. A service is immaterial, not transportable, not producible in advance and not storable. It follows the uno-acto-principle, which describes the simultaneous delivery and use, and integrates the external factor, i.e. the customer. Industrial services are considered in the context of IPS². These are services which are provided for the purpose of producing or selling economic goods or values.

5 INTERDEPENDENCIES BETWEEN THE IPS² ELEMENTS

In order to aid the developer with the creation of the product-service modules during the drafting stage, appropriate tools and methods are required. The development support has to address two main areas: The domain-specific characteristics and differences of the IPS² elements, and the detailed interdependencies between them. The various domains, which the IPS² elements belong to, have very different properties. In particular the service domain, with its immaterial process characteristics and the uno-actu-principle, differs substantially from the domains of the product elements. Therefore, dedicated tools and methods should be used for the development of each IPS² element in order to make use of the established and accurately fitting solutions. However, the existing tools and methods need to be adapted.

For an integrated development of IPS², it is essential to consider and model the interdependencies between all IPS² elements in detail. The different product and service elements depend on and influence each other and, therefore, need to be developed simultaneously as an integrated system. The design of a physical product, such as a machine part, determines the necessary pertinent services like maintenance and logistics, and the user training needs to transmit knowledge about the available

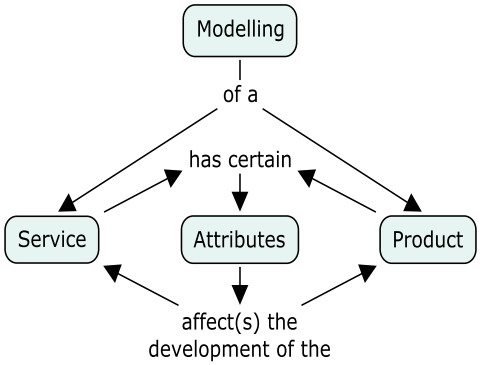

Figure 2: Interdependencies between product and service elements of IPS².

features of the machine control system. On the other hand, offering a service like condition monitoring requires the use of sensor technology and a special housing design.

These examples lead to the general concept of the inter-dependencies between IPS² elements, which is represented in a concept map in figure 2. The impacts, dependencies, compatibilities and interferences, with which the IPS² elements are interrelated, operate on different levels.

5.1 Content interdependencies

Looking at the entire Industrial Product-Service System, several levels of interdependencies can be identified. The concept map in figure 3 shows the structure of the IPS² elements with the named, solid links and the interdependencies between the elements and their attributes with the dashed lines. Starting at the highest level within IPS², the interdependencies between product-service modules concern compatibility (e.g. interfaces) and relationships requiring or enabling another PSM. The elements of the PSM are products and services, which in turn consist of components and process steps, respectively. The interdependencies between them result from their assignment and associations. The interdependency between a process step and the resources needed to execute it, is implied in their linking connection. All of these elements can have inter-dependencies with another element of the same type, which is depicted by the self-referring interdependency lines. The attributes of the elements mentioned above form the most detailed level. Examples for interdependencies at the attribute level are:

- The jaw width of a wrench has to be identical with the head width of a hexagon screw (resource attribute – component attribute).
- The duration of a setup process depends on the complexity of the machine control system (process step attribute – product attribute).
- The qualification of a training manager needs to meet the product type deployed (resource attribute – product attribute).

5.2 Process interdependencies

The content interdependencies described above lead to interrelations during the development process. Decisions during the development of a domain-specific IPS² element depend on decisions from the line of development of an associated IPS² element. The project management distinguishes between project sections that are processed strictly sequentially, and project sections which can overlap or even run simultaneously [11]. If one project section bases entirely on the result of another, a sequential arrangement is inevitable. Independent developments can be parallelized. Parallelization of processes with interdependencies requires synchronizing mechanisms. Due to short innovation cycles, a high degree of parallelism is desirable.

The process interdependencies can be classified into the assignment of development orders and the synchronisation of simultaneous lines of development. Figures 4 and 5 show two cases how development orders are assigned to the domain-specific developer teams. Figure 4 depicts an assignment to parallel lines of development which results from the IPS² concept. At an abstract level product-service modules are identified and described. For each domain-specific IPS² element contained in the PSM, a line of development can be initiated at the start of the drafting stage.

Because many interdependencies cannot be recognized in the IPS² concept or emerge with increasing detail during the drafting stage, an assignment of a development order for an IPS² element type can occur during the development within a different domain. Then,

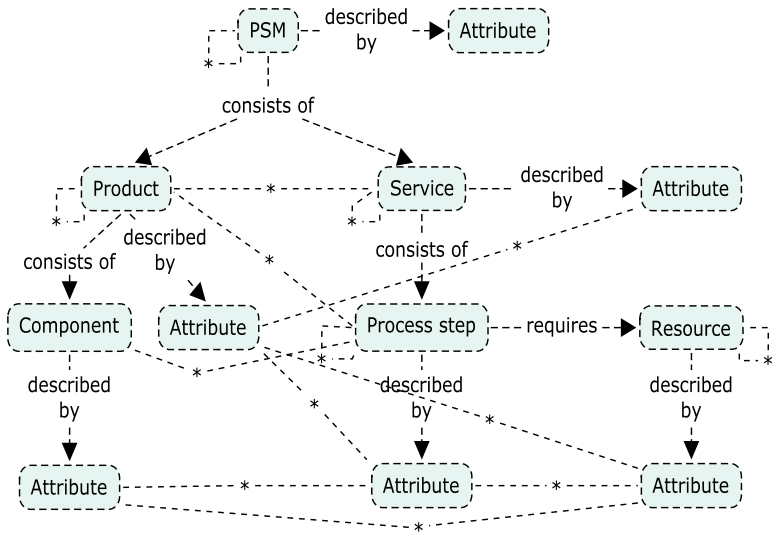

Figure 3: Content interdependencies between IPS² elements ranging from module level to attribute level.

an additional line of development is created, which could not be planned at the start (Figure 5).

Development tasks with interdependencies can often be processed simultaneously or overlapping each other. To do so, information regarding the interdependencies has to be exchanged. In figure 6 a demand for information about the development of IPS² element X arises, which is needed for further development of IPS² element Y. In this case a simple request-and-answer loop is sufficient, because of the unidirectional dependency between both elements. This “pull” mechanism is complemented by a “push” of information, when a development decision is known to affect the development of another IPS² element (Figure 7).

A synchronization of lines of development is necessary when decisions depend on the result of a parallel development. If an IPS² element cannot be further developed without information or the result from the other line of development, the process has to halt until this information is available (Figure 8). An alignment of processes takes place when a mutual synchronization is required due to bidirectional dependencies (Figure 9). The following triggers can be identified:

- Scheduled long-term alignments are defined in the course of project planning at system level.
- Scheduled short-term alignments can be set up during the assignment of additional development orders.
- On demand alignments are initiated by the development teams when unforeseeable changes are necessary.

6 IT SUPPORT FOR THE INTEGRATED PRODUCT AND SERVICE DEVELOPMENT DURING THE DRAFTING AND DESIGN STAGES

The main aspect to develop the product and service elements forming a product-service module is to consider the aforementioned interdependencies simultaneously and in an integrated manner. For this, the inter-dependencies have to be detailed and modelled at the levels ranging from the PSM down to the attributes of components, process steps and resources. Dedicated discipline-specific tools and methods for the development of each IPS² element need to be adapted to the purpose of providing this modelling functionality at a very detailed level during the drafting and design stages.

A key point for providing IT based development support lies in managing and reducing the complexity of such integrated modelling and development. Therefore, the user, i.e. the IPS² developer, needs to be able to easily overlook and grasp the effects of development decisions and the intricate interdependencies. A visual representation, which encapsulates detailed information and presents it on user interaction, may aid in this task.

The IT based support for drafting product-service modules is being developed as a software module of the IPS² assistance system (see section 3). At present the development support focuses on the disciplines “mechanics” and “services” in order to demonstrate the concept’s feasibility.

The integrated development of product and service elements, and the modelling of their interdependencies are implemented by fitting the services into the graphical representations of 3D-CAD models. The Computer Aided Design (CAD) approach has been well established in product development for decades. It is extended with service aspects and connected to the service modelling.

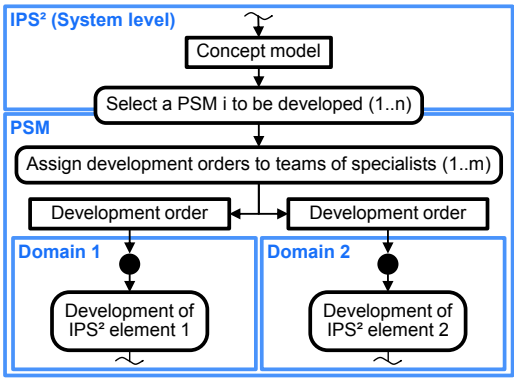

Figure 4: Planned assignment of development orders.

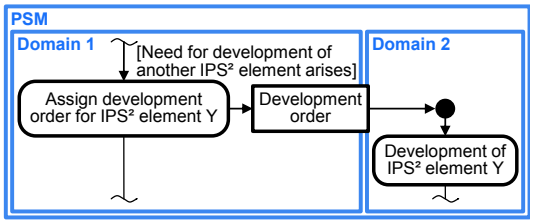

Figure 5: Assignment of development orders on demand.

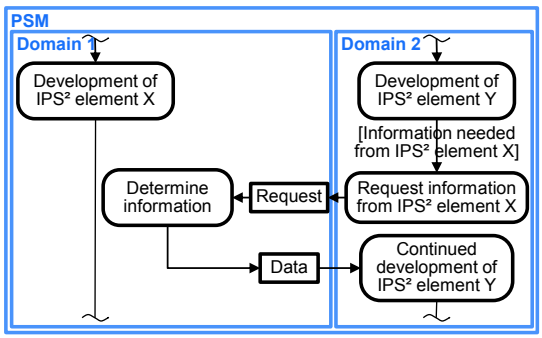

Figure 6: Information exchange between lines of development (Pull).

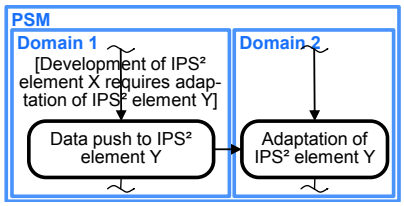

Figure 7: Information exchange between lines of development (Push).

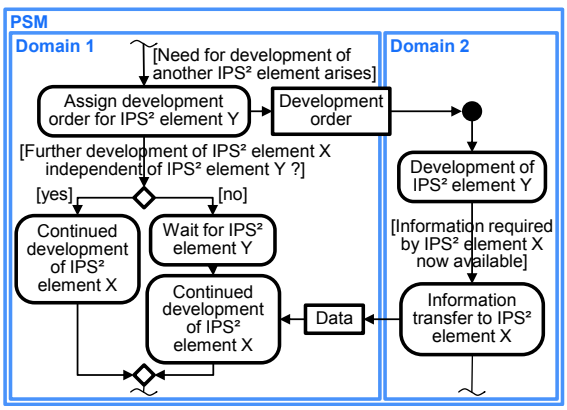

Figure 8: Synchronization of lines of development.

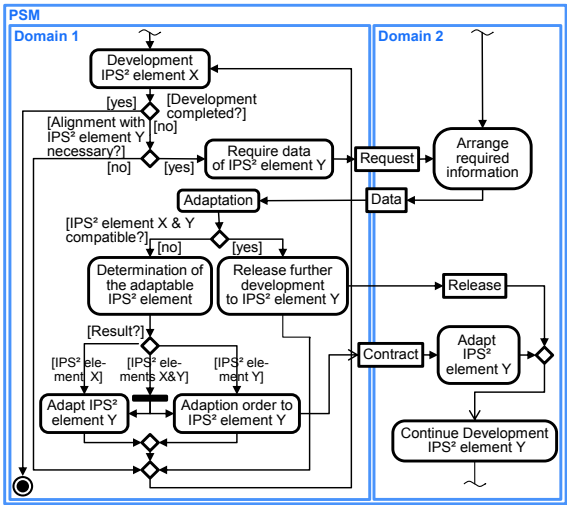

Figure 9: Alignment of lines of development.

6.1 Visualization of services in 3D product model

The service integration in the CAD system is visualized by a systematic, clear and comprehensible symbolism, which is assigned to specific product components in the product model and linked graphically in a 3D-CAD drawing. Pictorial symbols in the form of icons represent a service or a process step. Figure 10 shows an example of this visualization. In this example a tool spindle and its pertinent services are connected and graphically presented. The roller bearings have interdependencies with an inspection and maintenance process to check and refill the lubricant, which is depicted by the icon of an oil can. The other pictograms stand for monitoring of the temperature at the stator and bearings, replacement of the tool retention as well as preparation and connection of the power supply.

The details of the interdependencies can be modelled and viewed by user interaction with these pictograms, e.g. by clicking with a computer mouse. In the same way the developer can switch from the mechanical modelling module to process modelling for the connected service element (Figure 11).

6.2 Classification of industrial services

Each pictogram symbolizes a category or type of service or process. Thus, a developer can get a quick view over the IPS² elements of a product-service module. For this purpose it is necessary to have a clear classification of services and an established association between service type and pictogram. A literature research has been conducted, which was mainly based on standards and guidelines from areas such as project management, conformity assessment, maintenance and quality management. This survey produced 13 service categories:

- Conformity assessment, e.g. auditing, certification,
- Acceptance test,
- Production,
- Quality management including quality planning, quality control, quality assurance, quality improvement,
- Maintenance, inspection, servicing, repair, overhaul, improvement,
- Planning and development,
- Assembly, disassembly,
- Adaptation,
- Information provision, e.g. data management, training,
- IT services,
- Financial services,
- Controlling and
- End-of-life services.

These categories will be revised and specified in more detail. Intuitively comprehensible pictograms with a high recognition value will be designed and assigned to each category.

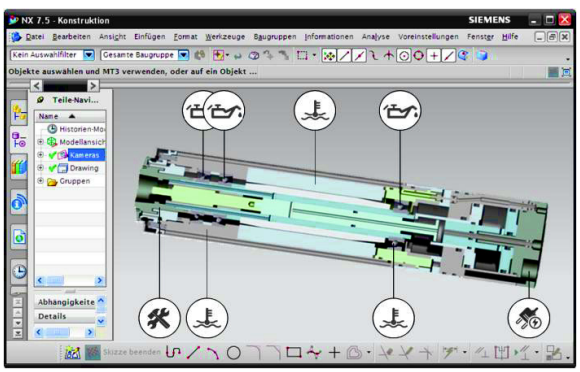

Figure 10: Visualization of services in 3D product model.

6.3 Implementation of the PSS-CAD development support tool

The PSS-CAD (Product-Service System-CAD) approach for the integrated development of product and service elements is being implemented as a prototypical software tool. The PSS-CAD tool is based on the established CAD system Siemens PLM NX for mechanical modelling aspects. The service and interdependency aspects will be written in the programming language C# with the Microsoft .NET framework and the NX Open Common Application Programming Interface (API).

In terms of reuse of development knowledge, standardization and modularization become very important. A standard database of product-service modules for a micro-production scenario will be built up. This standard module library also permits the validation of the aforementioned methods and the IT-based support tool.

7 SUMMARY

Industrial Product-Service Systems (IPS²) consist of interacting product and service elements. During the IPS² development process both elements, with their very different characteristics, appear for the first time in the conceptual stage, and in a concrete form in the drafting and design stages. Based on the functional model, product-service modules (PSM) are developed to meet the IPS² requirement specifications. PSM consist of variable elements of physical products and intangible services, which need to be developed simultaneously and jointly under permanent consideration of their interdependencies.

Support tools are necessary in order to aid the IPS² developer in coping with the increased complexity of the integrated, multi-domain development. He needs to overlook and grasp the effects of development decisions, thus gaining a better understanding of the parameters and the intricate dependencies between both elements of product-service modules as early as possible. At present such IT support does not exist.

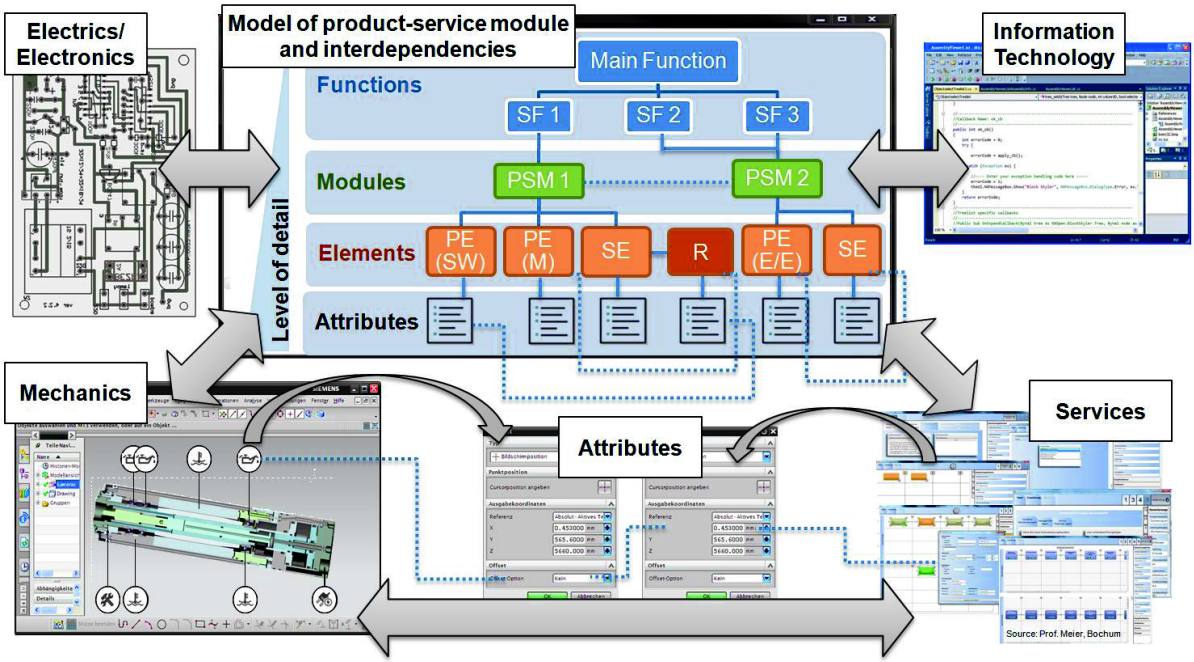

Figure 11: PSS-CAD: Integrated product and service development.

This paper presents a methodical approach to the integrated product and service development during the drafting and design stages, as well as a concept for the implementation in an IT-based development support tool. The approach is based on a method modelling and visualizing the interdependencies between the elements of one product-service module, and between different product-service modules. Thus, a model of interactions and relations is created that describes the integration of the product and service elements in high detail. The PSS-CAD support system provides the authoring tool for creating, visualizing and maintaining this model while the domain-specific IPS² elements are designed, and thus allows for an integrated product and service development for the drafting and design stages. As a software module within the IPS² assistance system, the PSS-CAD support system completes the IT support tool-chain for the entire IPS² planning and development process.

8 ACKNOWLEDGMENTS

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