Chapter 9
A STEP-compliant Online Product Digital Library for Customized Products

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Abstract Nowadays, small and medium-sized manufacturing enterprises (SMEs) are facing intensive competition from the global market. For these SMEs, how to better manage and record the previous product development knowledge has become a core issue for them to improve their product development process, cut down development costs, and reduce lead time. In recent years, considerable effort has been placed on developing new enabling technologies for SMEs to achieve high quality and productivity, and quickly responding to changing markets to meet customer requirements. This chapter presents our work in developing a STEP-compliant online product digital library for rapid development of high value-added customized products. The chapter focuses on how to develop the product digital library for digitizing various types of customized products. This library uses the standard for the exchange product model data (STEP) as a foundation. New methods and tools are developed to model, record, and search information such as customer requirements and expectations, engineering responses, product design, decision making, and product machining processes, *etc*. The recorded product information and knowledge in the library can be reused for the development of new customized products.

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Abbreviations

APs	Application protocols
CAD	Computer-aided design
CAPP	Computer-aided process planning
CIM	Computer integrated manufacturing
EDM	Express data model
LCP	Library of customized product
LCR	Library of customer requirements and expectations
LEV	Library of engineering voice
LMR	Library of machining resources
PDMS	Product data management system
SME	Small and medium-sized manufacturing enterprise
STEP	Standard for the exchange product modeled data

9.1 Introduction

Manufacturing markets have become more and more competitive and customer-driven in recent years. To survive and thrive in this competitive environment, manufacturing companies must utilize state-of-the-art technologies to improve all aspects of product development processes. It is essential to find globally optimized processes that can shorten the product life-cycle, reduce cost and lead time, and achieve high quality and productivity. This requires product data, information, and knowledge to be efficiently managed and utilized in a product life-cycle. As a reaction to the change in the market scenario where manufacturing is more costumer oriented, emphasis on using the Web to transfer knowledge and data within various entities of the product development cycle is increasing. The idea of integrating various users in the distributed product development process through the Web is a promising strategy for companies being forced to react to the growing individualization of demand, which has been addressed by Xie *et al.* (2003) and Li *et al.* (2004).

The main theme behind mass customization is to develop products that meet individual customer needs. This is generally closely tied to advancements in technology and its potential capabilities. The use of a product knowledgebase, which is a special kind of database to support product development, is a promising approach; however, the issues are still not fully solved in terms of how to develop an online product knowledgebase that is compatible, expandable, and able to integrate product information in various stages. There are some limitations of conventional technologies to meet the requirements of mass customization. They are (1) the *problem of integration*: conventional systems have normally been used to support the integration of one or two systems such as a computer-aided design (CAD) or the computer-aided process planning (CAPP) system. However, they cannot be directly used in the integration of the systems that are employed in other stages of product development processes such as customer interaction and engineering response to customers. (2) the *problem of cooperation:* many customized products are complex and are usually developed by combining the strength of several manufacturing companies, hence, data exchange and sharing between these companies should be very efficient and effective.

Most SMEs either do not have a product knowledgebase or structure their products using different modeling methods. Hence, it has become a challenge for them to cooperate with each other in support of the development of a particular product. Normally, an extra data conversion process should be carried out. This is very inefficient. Sometimes, conflicts about the model structures may even cause loss of information that cannot be converted. Therefore, a non-compatible system has become a barrier for collaborative development of customized products where cooperative efforts are required.

This chapter tackles the abovementioned issues and focuses on solving the following two issues: (1) how to digitally model customized products, and (2) how to take into consideration customer requirements, manufacturing constraints, supplier capabilities, and shop floor resources at the product design stage. The main objective is to develop a STEP-compliant online product digital library that can:

1. Record historical product data, information, and knowledge. The library will be used by SMEs to record their product development experiences including successes and failures, general product information, customer information, and development knowledge, *etc*.
2. Provide online tools for supporting product development processes. Online tools will be developed for users to record, search, and model various types of products. The developed library can be used as an on-line data and information library for design engineers. Evidently, through these useful tools, engineers and managers can easily and quickly source the necessary data and information.
3. Provide interfaces facilitating communications between customers and engineers. Efficient communication between a company and its customers is always important in order to develop a product quickly and meet customer requirements. The library will develop online customer interfaces for customers to interact with the company.

This chapter presents our work in developing a STEP-compliant online product digital library. First, a number of recent developments are discussed. The system architecture and a STEP-compliant product digital library are then introduced. Finally, case studies are conducted to demonstrate the feasibility and the compatibility of the proposed methods and tools.

9.2 Literature Review

STEP is currently considered a promising product modeling resource since it provides a standardized mechanism for product model data representation and exchange. Considerable research effort has been placed on how to develop STEP compliant data models, methods, and tools for supporting various product development activities. Yang *et al.* (2008) gave a comprehensive review on product modeling. Gu and Chan (1995) introduced a STEP-based generic product modeling system that was designed and implemented according to the generic resources of STEP and could thus be used to integrate manufacturing activities, such as process planning and inspection planning in the concurrent engineering environment. They presented an object-oriented approach for building product models for supporting product design. Their focus was placed on the definition of classes and the design of the user interfaces with CAD software tools. However, there were no discussions on the definition of the schemas and the knowledge modeling methodologies. Li *et al.* (1996) developed a feature-based parametric product modeling system, which employed a product model based on STEP and was managed by an object-oriented database. This system was suitable for application in a computer integrated manufacturing (CIM) environment. A STEP-based object-oriented product model based on STEP AP 224 was proposed by Usher (1996). This model was proposed for supporting CAPP analysis. A STEP-based part information model was developed for process planning purpose by Ming *et al.* (1998). Their models included a process planning information model and a production resource information model. Tang *et al.* (2001) presented a STEP-based die and product integrated information model (DPIIM), in which integrated resources of STEP were utilized to model six EXPRESS schemas. These models could support the concurrently developing stamp and die products. Zha and Du (2002) presented a product data exchange using STEP (PDES)/STEP-based assembly model for the concurrent integrated design and assembly planning.

It can be concluded that STEP has become the core of product modeling processes to organize product data in the standardized representation, which greatly enhances the capability of data exchanging and sharing in the integrated manufacturing environment. To utilize the modeling resources defined in STEP, various methods are integrated with STEP to form an integrated product modeling environment.

Application protocols (APs) are used for building up information models for the integration of STEP with different geometric modeling methods, such as AP204 addressed by ISO 2002 and AP203 addressed by ISO 1994. AP 203 integrates five types of shape representation methods that include wireframe and surface without topology, wireframe geometry with topology, manifold surfaces with topology, faceted boundary representation, and boundary representation to support the configuration controlled 3D design of mechanical parts and assemblies. For example, Shaharoun *et al.* (1998) utilized STEP to describe geometric data of a particular plastic product. The geometrical descriptions of the product were transferred into a CAD system to assist the design and machining of a suitable mold for the plastic product. Cai *et al.* (2002) proposed a method to build self-defined APs for all kinds of machine parts based on STEP. They implemented this method to develop two APs for presenting the geometric data model of the cone gear product for final driver of automobile driving axle system.

STEP also provides a suitable representation method for different features. For instance, AP224 introduced by ISO 2005 illustrates the mechanical product definition of process plans using *machining features;* AP224 and AP218 introduced by ISO 2004 also contain the STEP expressions for the specific features in the particular application areas. The entity defined in STEP can be directly utilized to represent the target features. Some self-defined features such as the special assembly structures, machining and technique information of some particular products, can be structured by using EXPRESS modeling language and integrated resources. Both STEP-defined features and self-defined features can optimize the data exchange and sharing capability of feature-based product modeling method. Typical examples of product modeling using the feature-based methods were introduced by Shah and Methew (1991), Meng *et al.* (1997), Zhao and Ma (1999), and Xie and Xu (2008).

There has been limited research work in developing STEP-based product modeling methods. For example, Chin *et al.* (2002) and Xie *et al.* (2008) proposed a multiple view methodology for integrated product modeling based on STEP. Song *et al.* (1999) utilized a STEP-based integrated product model to support the proposed design for manufacturing system. The aim was to extract the design information of parts from a CAD system for automatically evaluating the manufacturability of those parts. Jasnoch and Haas (1996) developed a collaborative working virtual prototyping environment to integrate existing CAD systems. The underlying product model of this environment was a STEP-based integrated product model.

The focus of this research is placed on modeling customized products, the definition of the knowledge structure, and the integration of the schemas with other resources defined within STEP. Schemas are defined to make sure that the proposed STEP-compliant digital library is compatible and can be used in modeling various types of customized products. These aspects, to the best of our knowledge, have not been studied extensively in literature.

9.3 System Architecture

The STEP-compliant online digital library provides input for supporting the design of customized products. The library is aimed at accumulating product development experience or knowledge for SMEs, and supporting collaborative, integrated, and concurrent product development, and capturing and responding to customer requirements. This library will be used to develop interoperability standards needed by SMEs to integrate the product design, planning, and manufacturing processes. The structure of the STEP-compliant online digital library is shown in Figure 9.1.

The library is composed of the library of customer requirements and expectations (LCR), the library of customized products (LCP), the library of engineering voice (LEV), and the library of machining resources (LMR). LCR is composed of customers' requirements and expectations and can be updated through an online customer interface. LEV records the technical attributes of a designed customer

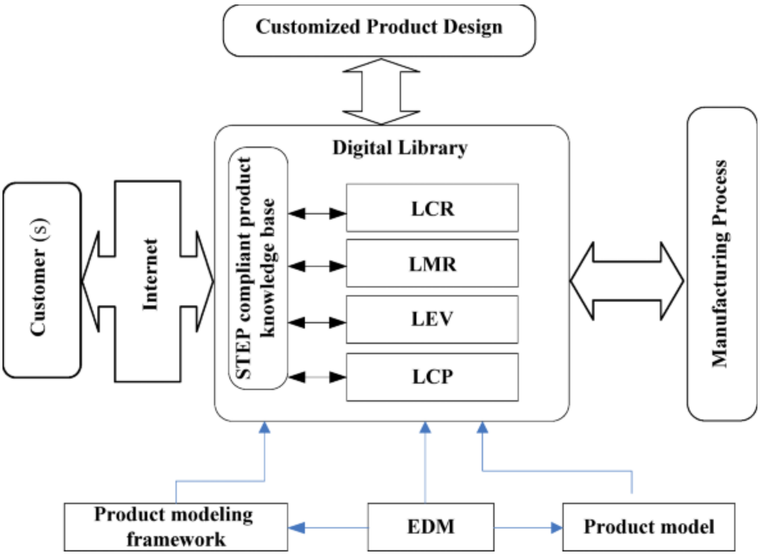

Figure 9.1 Structure of the system platform

product in response to its requirements and expectations. LMR includes the machining and manufacturing resources available in a company. LCP records all the information related to a particular customized product including geometric information, machining information, constraints, cost, lead time and knowledge, and issues related to the development of the product. The following are the basic modules and tools developed for interfacing with the library: (1) an Internet-based software platform, (2) global customer interfaces, (3) an Internet-based integrated product development environment, (4) an Internet-based product design environment for supporting product design, (5) an Internet-based virtual process planning/ assembly environment, (6) an Internet-based virtual simulation platform, (7) an Internet-based virtual manufacturing platform, (8) Internet-based design/manufacturing product data /knowledge bases and tools, and (9) a global cost estimation and optimization tool. The modules and tools were introduced in detail in previous research papers by the author (Xie *et al.* 2003, Zhou *et al.* 2007, Tu *et al.* 2007).

The product digital library is developed based on the four functional components including an EXPRESS data model, EDM, a STEP-based modeling environment, a 'five-phase' modeling method, and three EDM data exchange and sharing methods. The EXPRESS data model (EDM) is the core of the modeling framework. The EDM defines a complete product data structure and uses the standardized data format. It consists of 11 defined EXPRESS schemas and STEP AP 203, which can be found in the papers by Xie *et al.* (2008) and Zhou *et al.* (2007). Each schema utilizes either STEP resources or STEP-based compatible resources defined by our research group to model a particular type of product information.

The STEP-based modeling environment is established for the digital library. Within this environment, a modeling language-EXPRESS and its graphical representation method EXPRESS-G are used to model product structure. STEP generic resources are utilized to model product information that is defined by STEP. STEP AP 203 is used to model product geometric information and there are also new modeling resources defined for modeling product information not covered in STEP. A 'five-phase' modeling method is proposed to build up the EDM. It defines a formal approach to logically organize all the tasks of building up the EDM in the modeling processes (Xie *et al.* 2008).

To develop this proposed STEP-complaint online product digital library for customized products, the modeling framework and product model structure are very important. In this chapter, instead of discussing the structure and the individual modules of the entire system, the author opts to discuss the knowledgebase structure, modeling framework, product models and knowledgebase implementation of EXPRESS model, and the development of the STEP-compliant online product digital library.

9.4 STEP-compliant Product Digital Library

Figure 9.2 shows our proposed data structure of the STEP-compliant online digital library for supporting the development of customized products. The digital library is made up of the following data components: a product module, a module describing its design process, a tools module, a resources module, and an operational data and suppliers module. The product module describes the product information;,the design processes module models various design stages of the product, and the tools and the resources modules describe the information of the tools used in developing the product and resources used; supplier information related to the product is modeled in the supplier module. The relationships between these modules are represented in Figure 9.2. The proposed structure provides the basic infrastructure for digitizing customized products and is used in the author's research group to establish the product design knowledgebase.

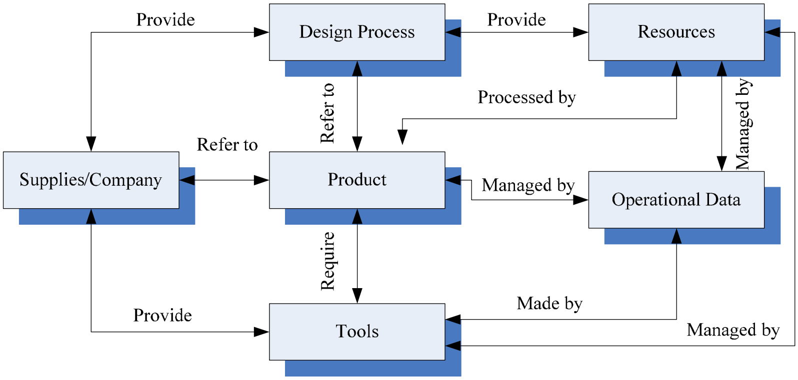

Figure 9.2 Data components in the product digital library

9.4.1 Product Knowledge Model

The product knowledge model as shown in Figure 9.3 is the conceptual description of ideas, facts, and processes that together represent the model of a customized product to be designed. The knowledge model contains four top-down information layers, which include a knowledge layer, a parts layer, a feature layer, and a parametric layer. The parametric layer contains products' geometric information. The feature layer contains all the feature information, which includes not only attributes but also relationships with other feature-level information objects and objects defined by users. The part layer contains all the part information that includes feature information and relationships among different part-level information objects. The knowledge layer contains not only parts information, but also "knowledge related" information objects and an inference engine. The knowledge in the knowledge layer is extracted from part-level knowledge and feature-level knowledge, which are formed by information objects and relationships among them. The knowledge in the knowledge layer can be directly used to support intelligent concurrent design and manufacturing. The management feature is used to manage all the information of a certain part, which can be saved and used as part of a company database. Application objects defined by users according to the requirements of the project can be put in the feature and part layer. After a new object is defined, its relationships will be created by either the users or automatically by the optimization algorithm and existing knowledge. This object with its relationships can be regarded as new knowledge, which can be used in new product design and manufacturing process.

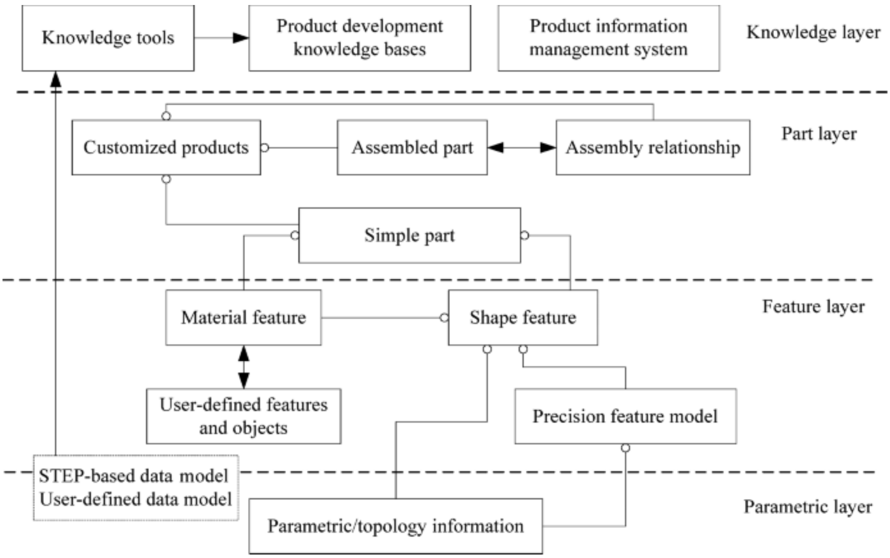

Figure 9.3 Product knowledge mode

9.4.2 Product Data Object

The object created in the product knowledge model is defined based on common concepts. There are groups of standard elements or information constructors that are used by every information model, which contain elements as follows:

1. *Entity* – construction that represents appearances from the real world.
2. *Property* – specific characteristic of entity, it could represent the numerical value, constraints, and behavior.
3. *Attribute* – certain property types setting restrictions on other properties or on whole entities.
4. *Relation* – implicit or explicit respect between two constructions in the model.
5. *Cardinality* – this defines the number of instances of one construction that can be linked with instances of the other constructions.

The entities and relations among them are the basics of the conceptual modeling. Also, the information models enclose the explicit group of the interpretation rules. The features that imply special demands on the information model are:

1. The uneven and variable structure of data.
2. The web like structure of the concept that is a result of the multiply links and dependencies.
3. The dynamic nature of data considering product development process.

The basic unit of the model is called a part. Such a part can be a piece that cannot be disassembled (called simple part) or a piece composed from two or more

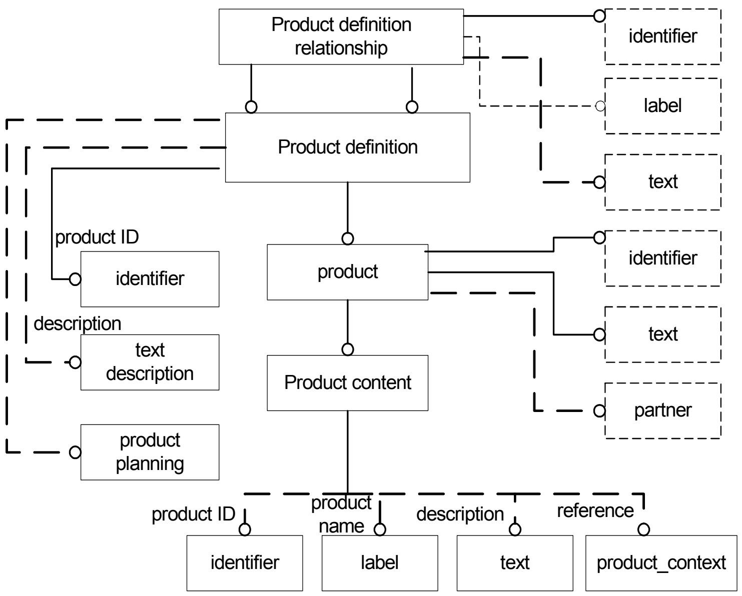

Figure 9.4 Product data description model

other pieces with defined relations between them. Four models are extracted from the product knowledge model: description model, geometric model, material definition, and feature model. The task of the description model is to define descriptive, non-geometric information about a product or assembly element. The entity product is the basic part of the description model and its purpose is to describe physical objects emerging from some process. The geometric definition of the product is the basic definition from which follows all the necessary information for analysis or product realization. The feature model is a variation of the geometric modeling, but due to the specific approach it is separated into a different model. The material definition model contains all information about materials that are necessary for the modeling or the product realization. Figure 9.4 presents a subset of entities for product structure description model using EXPRESS-G.

This model is very complex because it contains extremely large amounts of information about a product. The majority of information is stored in geometry and features models and this is the reason for simplifying the model for product structure description.

9.5 Case Study

Case studies are conducted to demonstrate the feasibility and the compatibility of the STEP-compliant online product digital library in digitalizing products from the different engineering applications. The rationality of the EDM and the relevant modeling methodologies are also tested. The clamp assembly product as shown in Figure 9.5 originated from a design project within the ENGINEERING tutorial book. Figure 9.5 shows a 3D solid model of this product, which is generated from Pro/ENGINEER® Wildfire® CAD system (Lamit 2004).

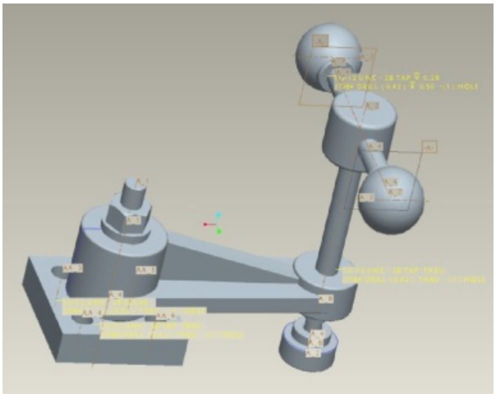

Figure 9.5 3D Model of the clamp assembly product (Zhou *et al.* 2008)

Figure 9.6 shows a tree structure model to demonstrate how this product model is assembled. The clamp assembly product consists of two subassembly components: a clamp and a plate. These two subassembly components are connected by the arm part. The subassembly clamp includes six components: an arm part, a swivel part, a foot part, a stud part, and two ball parts. The subassembly plate includes four components: an arm part, a plate part, a stud part, and a flange nut part.

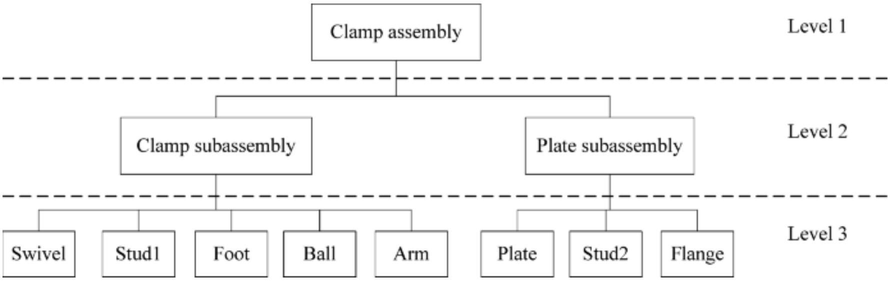

Figure 9.6 Structure of clamp assembly product (Zhou *et al.* 2008)

Three EDM data exchange and sharing methods, which were introduced in Xie *et al.* (2008) and Zhou *et al.*(2007) are used to model different aspects of product data of the sample product.

1. Product geometric data and product general information of the sample product are modeled into STEP Part 21 files. These two products are utilized to test product geometric data module and the *product_definition_schema*.
2. The product inspection data of the sample product are modeled as the STEP objects by an application C++ program. This is to test the *inspection_information_schema* defined in the EDM.
3. A prototype online digital library is developed to represent product data. The manufacturing processes of the assembling data of the “clamp assembly product” are modeled. They are utilized to test the *process_planning_schema* defined in the EDM.

9.5.1 Modeling Product Inspection Information

The inspection data of the product were modeled based on the working form ROSE C++ library. Through the integrated developing software environment that consists of ST-Developer and Microsoft Visual C++, the inspection data are modeled into STEP objects. This case study is carried out by following the above three steps. The product inspection information are modeled into STEP objects and presented as a STEP Part 21 file.

1. The inspection_information_schema is converted to C++ class definitions through EXPRESS Compiler in ST-Developer® as shown in Figure 9.7. Meanwhile, as the product_definition_schema and product_document_schema are referred by the inspection_information_schema, these two schemas are converted to C++ codes as well. The six corresponding ROSE schema files, inspetion_information_schema.rose, inspection_information_schema_EXPX.rose, product_definition_schema.rose,product_definition_schema_EXPX.rose, product_document_schema.rose, and product_document_schema_EXPX.rose are generated.
2. The functions and variables in these C++ codes and the data-dictionary in the *.rose files are utilized to generate the application ROSE C++ program.
3. The STEP objects are displayed in the command window and outputted in a STEP Part 21 file. The manipulations of these two STEP objects are realized by utilizing the functions ROSE.display and ROSE.saveDesign defined in the ROSE Library. Figure 9.7 presents the screen snapshot of ROSE.display( ) results.

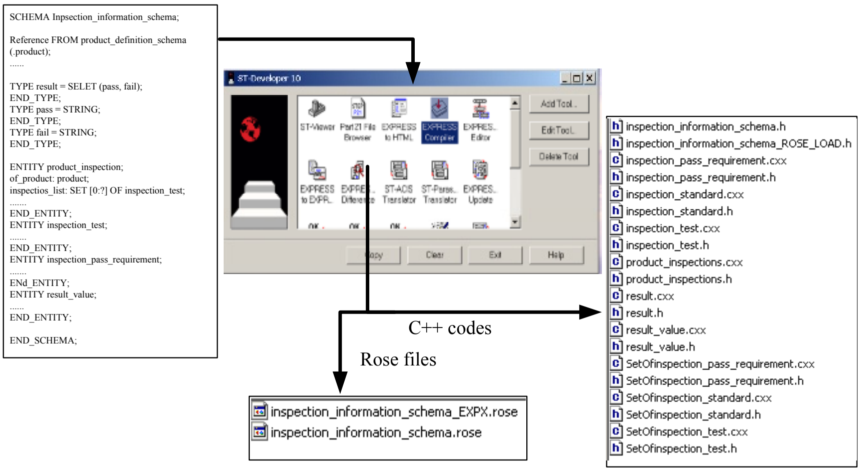

Figure 9.7 Converting inspection_information_schema into C++ classes and ROSE schema file (Zhou *et al.* 2008)

There are 19 STEP objects created in this case study, from <0–0> to <0–18>. These STEP objects are built up based on the *inspection_information_schema*, *product_definition_schema* and *product_document_schema* in the EDM.

The STEP objects <0–0> to <0–2> are the three instances of *inspection_pass_requirement* in the *inspection_information_schema*. The STEP objects <0–3> to <0–5> define three instances of the *SetOfinspection_standard*. The STEP objects <0–6> to <0–8> present the three instances of the *inspection_standard* in the *inspection_information_schema*. The STEP object <0–9> defines the product data for an instance of *document_type* in the *product_document_schema*. The STEP objects <0–10> to <0–12> present the three instances of *result_value* in the *inspection_information_schema* for three inspection tests modeled in STEP objects <0–14>, <0–15>, and <0–16>. An instance of *result* in the *inspection_information_schema* is modeled into STEP-object <0–13>.

There are three instances of *inspection_test* in the *inspection_information_schema*. For example, in the STEP object <0–14>, the *id*, *name*, and *description* are valued as "lid-inspection001" and "open torque test", respectively. The *test_product* is valued by STEP object <0–17>, which stores the definition of the product. The *frame_of_reference* utilizes the STEP object <0–3> to define the referring standards. The other two instances *inspection_test*, STEP objects <0–15> and <0–16> are defined in the same way.

The STEP object <0–17> is an instance of *product* in *product_definition_schema*. The *of_category* utilizes STEP objects <0–18> to define the product category data about the *product* modeled in STEP object <0–17>.

9.5.2 *Online Product Digital Library*

A prototype online digital library named product data management system (PDMS) is developed by using the third EDM data exchange and sharing method. All product data will be stored and managed by this system. The prototype library consists of two parts: a product data interface and a product knowledgebase. These parts are both developed and based on the EDM.

9.5.2.1 Product Data Interface

This interface has two main functions. The first is to support inputting product data into the product database. The second is to manipulate product data including data querying and data updating, which is based on the support of Microsoft Access. These two functions are presented on two separated windows: data input window and data query window. Their layouts are organized according to the schemas structure of the EDM. Figure 9.8 shows four kinds of product data input windows for product general information, product inspection information, product manufacturing process information and product assembly information. A data query window is also developed to enable users to search the PDMS. The query field can be chosen from the pop-up menu. The query key word can be inputted from the blank input field and served for data query after clicking the "submit" button. The query results are presented using an excel table or form.

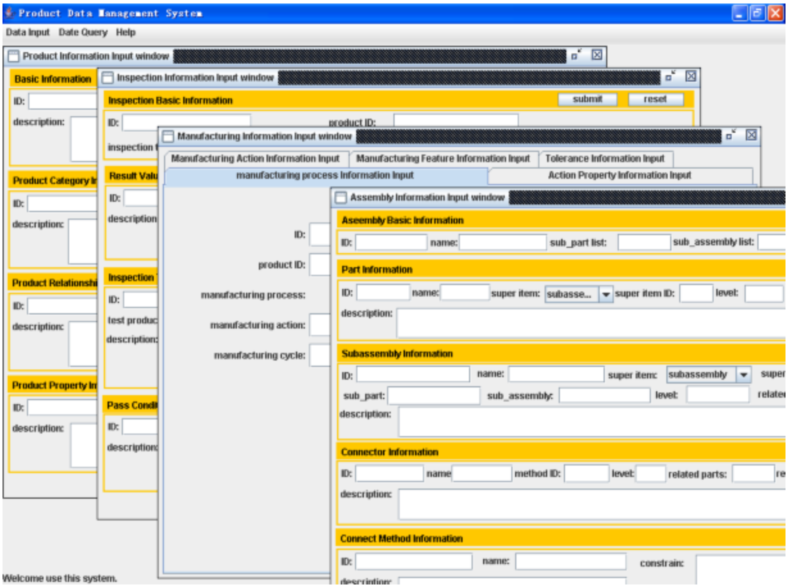

Figure 9.8 Product data input window and query window (Zhou *et al.* 2008)

9.5.2.2 STEP-compliant Product Knowledgebase

The main functions of the product database are: (1) storing the product data following the structure defined by the EDM, and (2) utilizing the Microsoft Access manipulate data. There are 19 tables in the proposed product database and they are categorized into four types: (1) the product general information, (2) the product inspection information, (3) the product assembly information, and (4) the product manufacturing process information. These tables are naturally associated with the corresponding schemas: the *product_definition_schema*, the *assembly_information_schema*, the *inspection_information_schema*, and the *manufacturing_process_schema*.

The structures of the above schemas are mapped into product database. There are two types of mappings: (1) that between EXPRESS ENTITY and the table in the product database, and (2) mapping the relationships between different EXPRESS ENTITYs to the corresponding tables in the product database. For the first kind of mapping, the attributes of an entity are mapped to the corresponding columns of a table. The name and the value type of the input field are mapped from the attribute definition. Figure 9.9a presents the first type mapping between *assembly_information_schema.assembly_proudct* and the table "assembly". The relationships between entities are also presented in between tables. Figure 9.9b shows the relationship between *assembly_information_schema.assembl_proudcty* and *assembly_information_schema.part*, which are mapped into two tables named "assembly" and "part".

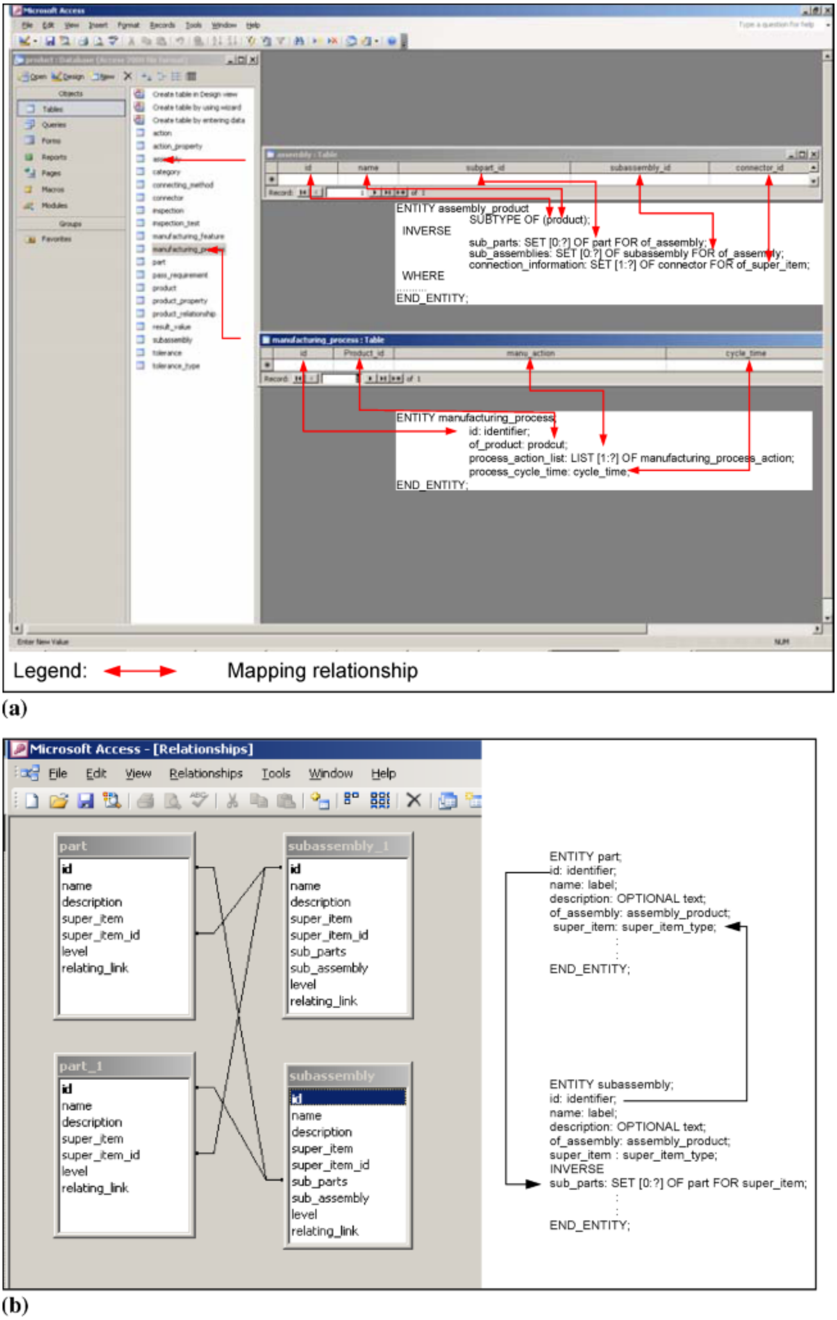

Figure 9.9 Mapping between (a) product database and (b) the EDM (Zhou *et al.* 2008)

9.5.3 Modeling Product Manufacturing Process Data

A lid is utilized to test the process_planning_schema through the prototype PDMS. This test utilizes the product manufacturing process data input interface and involves six access tables: action, action_property, manufacturing_process, manufacturing_feature, tolerance, and tolerance_type. They are built based on the process_planning_schema.

In this case study, all data of the manufacturing process of a water bottle lid are modeled. There are seven steps to manufacturing a product such as the water bottle lid. The second manufacturing step, “injection”, is modeled through the PDMS shown in Figure 9.10. The product data of this step are inputted through the manufacturing action information input window (see top of Figure 9.10); they are stored in the product database table “action” (see bottom of Figure 9.10). The product data of this step are demonstrated as: (1) “step002”; (2) “injection process”; (3) “injecting 2.4*24g melted HDPE to the cavity”; (4) “property 001” and “property002”, which are 210° and 840 bar, respectively; (5) 0.8 s; (6) “nozzle”, “24-cavity mold”, “HUSKY S160”; (7) none; and (8) 2. These eight data elements correspond to the eight attributes of manufacturing_process_action. The arrows show this mapping relationship. The product data of the other six steps are inputted into the STEP-compliant product knowledgebase as presented in the “action” table in the Figure 9.10.

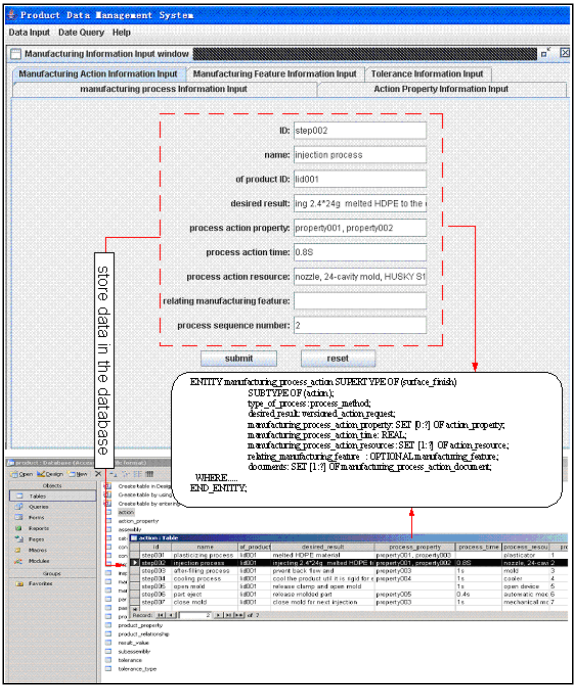

Figure 9.10 Modeling the “injection” step of the water bottle lid product (Zhou *et al.* 2008)

9.5.4 *Modeling Product Assembly Information Data*

The product assembly information of the clamp assembly product is utilized to test *assembly_information_schema* through the prototype product knowledge-base. This test utilizes the product assembly information input interface and it involves five Access tables: assembly table, part table, subassembly table, connector table ,and connecting_method table. They are built up based on the *assembly_information_schema*.

Figure 9.11 shows a user interface for inputting product assembly information. There are five fields, which are structured based on the corresponding entities in the *assembly_information_schema*. For example, the first input field named “assembly basic information” is generated by mapping the structure of the *assembly_product*. Its input “ID”, “name”, “sub_part_list”, “sub_assembly_list” and “connector ID” refer to the five attributes of *assembly_product*: *id*, *name*, *sub_parts*, *sub_assemblies*, and *connection_information*.

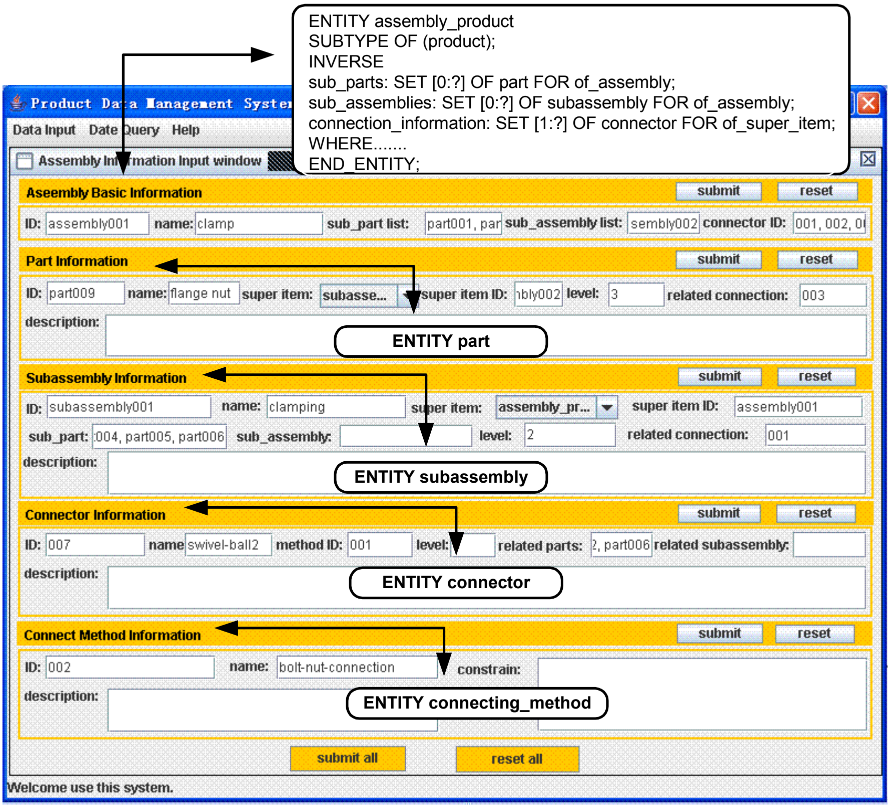

Figure 9.11 Assembling information input (Zhou *et al.* 2008)

Figure 9.12 shows the detailed search results of nine instances of the product *clamp*. There are nine components of the clamp product. For example, as for the flange nut part, its product data are presented as: “part009”, “flange nut”, “ ”, (“subassembly”, “subassembly001”), 3, and 003. They are sequentially matched to the attributes of *part*, which are *id*, *name*, *description*, *super_item*, *lever_in_assembling_hierachy*, and *connection_information*.

The product data can be retrieved from the digital library. For example, as for the “part009” shown in Figure 9.12, the “super_item” is “subassembly” and the “super_item_id” is “subassebly002”. The detailed information of “subassembly002” can be retrieved by querying in the subassembly table. The “part009” is listed in the “sub_parts” column. This example presents the relationship between *subassembly* and *part*. The *super_item* attribute of *part* can be valued by an instance of *subassembly*; the *sub_parts* attribute of *subassembly* is defined by a set of instances of *part*.

Figure 9.13 shows a summary of all the assembly data about the clamp product, which are stored in the five tables (assembly, subassembly, part, connector, and connecting_method) of the product database in the prototype PDMS.

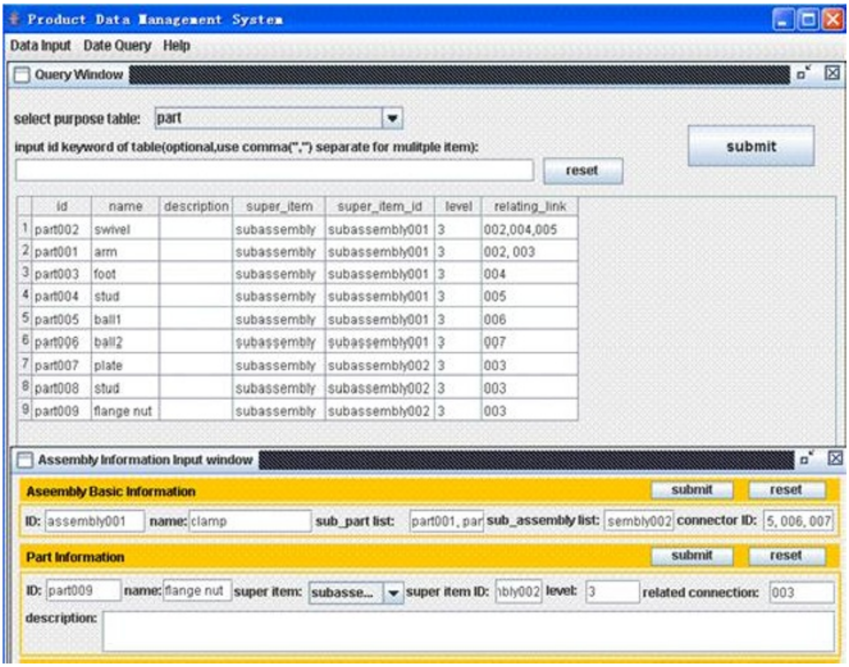

Figure 9.12 “Part” data querying results (Zhou *et al.* 2008)

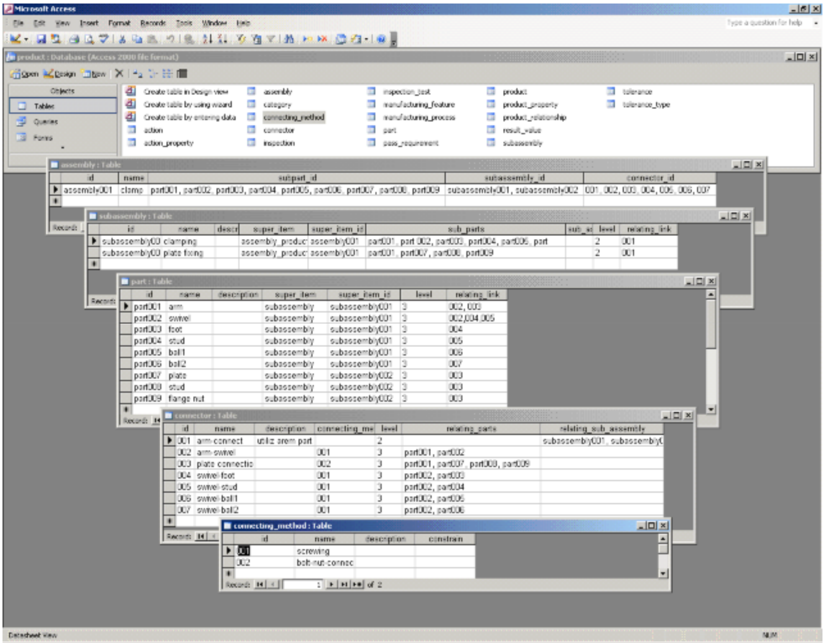

Figure 9.13 Assembly data of clamp product stored in the PDMS (Zhou *et al.* 2008)

9.5.5 Discussion

Interfaces are designed for interacting with customers in real time within the developed prototype digital library. Through the interfaces, customers can directly input their enquiries and make changes to their requirements and expectations. The information will be fed into the company through the online system, and engineers will start a search through the digital library. The search process will check whether the company has developed similar products before. The search is carried out using a combined method involving both customer requirements (*e.g.*, keywords used) and engineer inputs (*e.g.*, feature or geometric information). If a similar product is found, its relevant information can be retrieved from the digital library, the design team can then start with this product. This greatly shortens the product development cycle and the company can respond to its customer enquiries quicker. The main advantages of developing the STEP-compliant online digital library for developing customized products can be summarized as following: (1) record of product development knowledge for reuse, (2) reduction of product development time, (3) better interaction with customers, and (4) quick response to customer changes. The STEP-compliant feature of the digital library also enables the integration of the entire product development process.

9.6 Conclusion and Future Work

This chapter presented a STEP-compliant online product digital library for rapid development of customized products. The focus of the study was to develop a STEP-compliant product knowledge base for digitizing products of different types. This is achieved through the definition of the schemas and the proposed product knowledge modeling methodologies. Case studies are carried out to validate the proposed modeling methods. A prototype online digital system has been developed to demonstrate how the library works. From the case studies, the following conclusions are drawn:

1. The proposed STEP-compliant online product digital library is compatible for digitizing products of different types. The examples from the case studies can be extended to different manufacturing applications. Through the product digitizing methods, the product data are modeled and stored in proper formats.
2. The online product digital library is able to support the modeling of a wide range of product data, especially the product manufacturing data. In the case studies, five aspects of product data are modeled through the proposed library. The corresponding product models provide a comprehensive view of the product.
3. The case studies show that all customized products are associated with the EDM. The entire product modeling processes is dependent on the data structure defined in this data model.
4. The EDM is flexible to be implemented. It has four modules. Each module of EDM, even each EXPRESS schema, can be considered as an individual EXPRESS data model. They can be applied with the EDM data exchange and sharing methods to model the corresponding product data. In three case studies, the product general information module, the product geometric data module, the *inspection_information_schema*, the *process_planning_schema*, and the *assembly_infomration_shcema* are utilized individually to support modeling product data.
5. The prototype system is developed to demonstrate how the proposed STEP-compliant online product digital library works with general database systems for modeling and managing product data. This is based on the third level of EDM data exchange and sharing method (Xie *et al.* 2008).

The STEP-compliant online product digital library provides a well established mechanism to support the integration of manufacturing systems through the proposed product modeling methodologies. However, more work needs to be carried out on developing tools for supporting the integration of product development systems. The future work in the area is enormous and not limited to the following three areas.

The first area is to further develop the prototype STEP-compliant online product digital library system. This includes the input/output interfaces for the integration of various computer aided systems, such as CAD, CAPP, and CAM. The system needs to provide a standard interface to transfer product data with proper format to the end user.

The second area is to further validate the proposed online digital library by applying it in modeling products of other types. Our research work in modeling sheet metal and injection molding products has shown that this is a complicated process (Tu and Xie 2001, Tu *et al.* 2007). Future work in this area requires great effort to define new schemas as STEP itself is still at its development stage.

The third is to explore the possibility of integrating the proposed online digital library with other Web/Internet-based manufacturing. This can enable the proposed library to be easily adopted by other Internet-based systems. The possible implementation method involves utilizing mapping between XML and EXPRESS, which is defined in STEP Part 28 by ISO (2003).

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References

Cai CT, Li YY, Dai YH, Liu XY (2002) Design method of application protocol of the machine parts based on STEP. Computer Integrated Manufacturing Systems 8:892–895

Chin KS, Zhao Y, Mok CK (2002) STEP-based multview integrated product modeling for concurrent engineering. International J of Advanced Manufacturing Technology 20:896–906

Gu PH, Chan K (1995) Product modeling using STEP. Computer-Aided Design 27:163–179

ISO (1994) Industrial automation systems and integration: Product data representation and exchange: Part 203: Application protocol: Configuration controlled 3D designs of mechanical parts and assemblies, Reference number: ISO 10303-203:1994(E), First edition, Switzerland.

ISO (2002) Industrial automation systems and integration: Product data representation and exchange: Part 204: Application protocol: Mechanical design using boundary representation, Reference number: ISO 10303-204:2002(E), First Edition, Switzerland.

ISO (2003) Industrial automation systems and integration: Product data representation and exchange: Part 28: Implementation methods: XML representations of EXPRESS schemas and data, Reference number: ISO 10303-28:2003(E), First edition, Switzerland.

ISO (2004) Industrial automation systems and integration: Product data representation and exchange: Part 118: Application protocol: Ship structures, Reference number: ISO 10303-118, First Edition, Switzerland.

ISO (2005) Industrial automation systems and integration: Product data representation and exchange: Part 224: Application protocol: Mechanical product definition for process planning using machining features, Reference number: ISO/DIS 10303-224, Third Edition, Switzerland.

Jasnoch U, Haas S (1996) Collaborative environment based on distributed object oriented databases. Computers in Industry 29:51–61

Lamit LG, PRO/ENGINEER® WILDFIRE™, Belmont: ThomsonBrooks/Cole, 2004 (Prickly-Paradigm: Chicago).

Li HL, Han JH, Dong JX, Wang Y (1996) Feature-based parametric modeling system for CAD/CAPP/CAM integrated system. J of Engineering and Applied Science 329–333

Li WD, Fuh JYH, Wong YS (2004) An Internet-enabled integrated system for co-design and concurrent engineering. Computers in Industry 55(1):87–103

Meng MC, Yang L, Bai LK (1997) Feature modeling system based on STEP. Computer Integrated Manufaturing System 3:34–38

Ming XG, Mak KL, Yan JQ (1998) A PDES/STEP-based information model for computer-aided process planning. Robotics and Computer Integrated Manufacturing 14:347–361

Shah JJ, Methew A (1991) Experimental investigation of the STEP Form-Feature Information Model. Computer-Aided Design 23:282–296

Shaharoun AM, Razak JA, Alam MR (1998) STEP-based geometric representation as part of product data model of a plastics part. J of Materials Processing Technology 76:115–119

Song YY, Cheng Y, Cai FZ, Xiao YB, Tang D (1999) Study on knowledge-based integrated design for manufacture of mechanical parts. J of Tsinghua University 39:21–24

Tang D, Zheng L, Li Z, Chin KS (2001) STEP-based product modeling for concurrent stamped part and die development. Computers in Industry 46:75–94

Tu YL, Xie SQ (2001) An information-modeling framework for sheet metal parts intelligent and concurrent design and manufacturing. International J of Advanced Manufacturing Technology 18(12):873–883

Tu YL, Xie SQ, Fung RYK (2007) Product Development Cost Estimation in Mass Customization. IEEE Trans on Engineering Management 54(1):29–40

Usher JM (1996) STEP-based object-oriented product model for process planning. Computers and Industrial Engineering 31:185–188

Xie SQ, Tu YL, Fung RYK, Zhou ZD (2003) Rapid One-of-a-kind Product Development via the Internet: the literature review of the state-of-the-art and a proposed platform. International J of Production Research 41(18):4257–4298

Xie SQ, Xu X (2006) A STEP-Compliant Process Planning System for Sheet Metal Parts. International J of Computer Integrated Manufacturing 19(6):627–638

Xie SQ, Xu X (2008) A STEP-Compliant Process Planning System for Compound Sheet Metal Machining. International J of Production Resdearch 46:25–50

Xie SQ, Yang WZ, Tu YL (2008) Towards a generic product modeling framework. International J of Production Research 46(8):2229–2254

Yang WZ, Xie SQ, Ai QS, Zhou ZD (2008) Recent Development on Integrated Product Modeling: a Review. International J of Production Research 46(21):6055–6085

Zha XF, Du H (2002) A PDES/STEP-based Model and System for Concurrent Integrated Design and Assembly Planning. Computer-Aided Design 34:1087–1110

Zhao W, Ma W (1999) Feature modeling for aeroengine blades according to STEP. J of Beijin University of Aeronautics and Astronautics 25:535–538

Zhou ZD, Xie SQ, Yang WZ (2007) A Case Study on STEP-enabled Generic Product Modeling Framework. International J of Computer Integrated Manufacturing 8(1):43–61