STUDY ON CONSTRUCTION OF FBS-MODEL BASED PRODUCT DESIGN ONTOLOGY

Yuefen Wang, School of Economics and Management, Nanjing University of Science and Technology, Jiangsu 210094, China, +862584315963, yuefen163@163.com
Wei Chen, Institute for Informatics Ludwig-Maximilians-Universit¨at M¨unchen Oettingenstr, 67 Munich 80835, Germany, ericwaynechen@gmail.com
Yonghua Cen, School of Economics and Management, Nanjing University of Science and Technology, Jiangsu 210094, China, +862584315963, yonghua.cen@gmail.com
Xiaojuan Shen, School of Economics and Management, Nanjing University of Science and Technology, Jiangsu 210094, China, +862584315963, shenxiaojuan1988@126.com

ABSTRACT

In this paper, through analyzing features of product design knowledge, we divide product design knowledge into several classes. Then, semantic relations and semantic framework in product design knowledge are specified using top ontology in SUMO. Further, based on FBS-model with semantic extensions, we construct ontology for product design knowledge. We also propose a modified seven-step construction method for product design ontology. Based on this method, we implement domain ontology and design ontology in Protégé.

INTRODUCTION

There are so many redesigns in product design. It requires cooperation between designers with different domain knowledge. It is necessary to reasonably schedule executive tasks of design activities. Also, product design gets involved in material choice, determination of product functions, design standards choosing, design procedure making, quality control, and defining application scenarios etc. Meanwhile, knowledge about functions, structures, design methods, diagrams, formulae, material, design procedures raises high requirements on designers. Hence, to organize, store, and share general knowledge such as well-known product designs and industrial standards, further, to extract, formalize, and represent design experience and knowledge of experts will be very helpful for product design.

“Ontology concerns conceptual and precise specifications” [2]. Its basic elements include: concept, property, relation, function, axiom, and individual. Since ontology has standard terms and precise semantics, in recent years, it has been exploited widely in representation and sharing of knowledge about product design. It can not only formalize domain knowledge of product design, but also describe product functions and relations between different behaviors. By doing this, knowledge of product design can be effectively shared.

Well-known methods of ontology construction towards product design can be classified as follows: FBS-model (function, behavior, and structure) based representation with its extensions [1][3], BDE-model based representation [11], life-cycles of product design based representation [6], and product properties based representation [7][10]. Among these methods, FBS-model based representation has been exploited widely since it has well-founded theoretical foundations and reveals relations between different components of product design in a better way. As Ruan et al. [8] pointed out, product knowledge is embodied on different abstract levels and representation of product knowledge needs to describe functions, behaviors, and structures of a product, and to capture constraints and relations on different levels. Hu et al. [4] studied S-B-F model for product knowledge representation. Further, flow ontology and function ontology were constructed in ontology description language. Based on this, they designed ontology-based knowledge representation for pump design. Some other researchers modified and extended FBS-model according to specific properties of objects to describe. For instance, Xu et al. [3] proposed function-behavior-structure-efficiency model towards ontology knowledge representation for maintenance of power plants. Further, a classification method was built for ontology knowledge within this domain.

Although a lot of progress has been made, there are still some gaps between theoretical construction and practical implementation: fundamental domain knowledge is weak in knowledge description for product design. In this paper, combining with requirements of practical product design, we investigate processes and methods of FBS-based ontology construction for product knowledge.

CONSTRUCTION PROCESS OF PRODUCT DESIGN ONTOLOGY

In this paper, ontology construction for product design includes domain ontology construction and design ontology construction. Figure 1 gives the main idea and flow chart of the ontology construction method we propose in this paper.

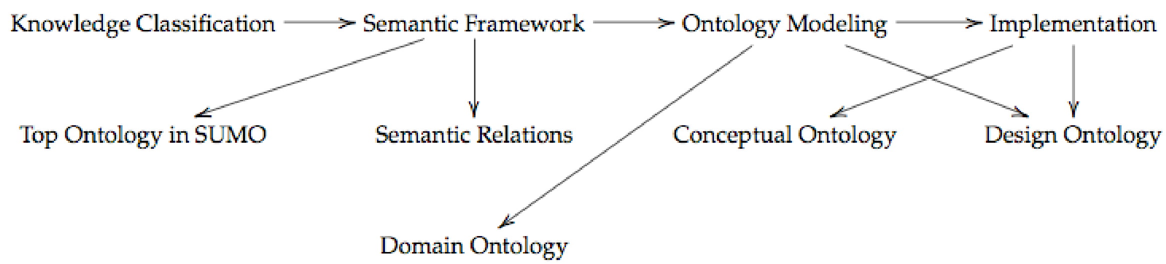

FIGURE 1: Construction Process of Product Design

In order to represent effectively and completely knowledge from product design, firstly, one has to have a clear idea about design knowledge to capture followed by analyzing and categorizing properties of product design knowledge; secondly, one needs to work out the framework for semantic description of product design ontology. We adopt top ontology in SUMO as basis with extensions to include richer semantic relations; then, we build models for ontology representation of product design knowledge. Based on FBS-models, we build and analyze our model for domain ontology and design ontology respectively; finally, we propose a seven-step ontology construction method for product design and implement it in Protégé.

ONTOLOGY MODELING OF PRODUCT DESIGN

Classification of Design Knowledge

Design knowledge is the collection of design experiences, design methods, design procedures, and product information such as geometric structures and properties etc. Design knowledge is classified as: individuals, experiences, manuals, formulae, constraints, diagrams and documents. In [5], design knowledge is classified as: design requirements, shape information, engineering information, organization information and design procedure information.

Generally speaking, without a standard classification, current classifications of design knowledge are based on different forms of knowledge appeared in product design. FBS-model describes knowledge of product design from three aspects: function, behavior, and structure. It also reflects connections between different components of design knowledge. That is, structures support behaviors, behaviors decide functions, and functions meet requirements of product design. Therefore, in order to express design knowledge in a better way, based on FBS-model, we classify design knowledge from three aspects: function, behavior, and structure. Table 1 shows FBS-based classification of product design knowledge.

TABLE 1: Classification of Product Design Knowledge

Classes	Descriptions	Examples	FBS-Models
Descriptive Knowledge	Structural features of products connections between properties	Principles, structures geometric properties	Structure model
Individual Knowledge	Known design results with design requirements and design procedures etc.	Components, individuals	
Design Guide Knowledge	Main tasks and aims with related guides	Tasks, principles, and methods	Function model
Judgment Knowledge	Relations between facts for reasoning	Cause-effect relations condition relations	Behavior model
Procedure Knowledge	Operations or sequences of operations	Tasks, operations and series of them	
Computational Knowledge	Parameters related to design procedures	Formulae, functions, and tools	
Manual Knowledge	Optional values or scopes for parameters	International/national/industrial standards or manuals	

Specification of Semantic Framework for Ontology

Research and construction of design knowledge ontology for a specific domain require to supply semantic framework and concept collection for domain knowledge description. We use top ontology in SUMO to specify semantic relations in product design ontology. SUMO was created by IEEE Standard Upper Ontology Working Group. It includes a collection of relations and axioms which can be used to define concepts and relations between concepts. Combining with requirements in product design, we define object properties and data properties as follows:

1) Object Properties.

Object properties in OWL ontology reveal relations in classes. Class relations are divided into: hierarchy relations and non-hierarchy relations. Hierarchy relations are based on tree structures which characterize internal structures within classes. Non-hierarchy relations are based on network structures which reflect relations between classes and individuals.

(1) Hierarchy Relations. Hierarchy relations include subsumption relations and part-whole relations. In ontology, the conceptual system is formed by extending subsumption relations and part-whole relations between classes. Among them, subsumption relations, that is, classifications of a concept, can be defined by adding subclasses. In OWL code, they are denoted by *subClassOf*. Part-whole relations represent constitutions of objects. They are represented by defining two object properties: *hasPart* and *isPartOf* which are reversed. For instance, the wheel *isPartOf* the car and the car *hasPart* the wheel. In order to express completely part-whole relations in product design, except for *hasPart* and *isPartOf* relations, we also use *contains* and

properPart relations to characterize the case: components made of some material have different functions.

(2) Non-hierarchy Relations. Conceptual non-hierarchy relations in ontology reflect intrinsic internal connections between objects. Non-hierarchy relations between ontology concepts include: synonymy relations, antonymy relations, metonymy relations, cause-effect relations, effect-cause relations, and positional relations etc. In this paper, we use well-defined relations in SUMO top ontology with some modifications for future extensions and reusing. Some non-hierarchy relations are shown in Table 2.

TABLE 2: Some Non-Hierarchy Relations

Type	Name	Type	Name
Physical Positions or Connections	top	Material Property	useMaterial
	connectedBy	Design Guides	hasDesignTask
Classification Relations	classifiedBy		hasDesignRequirement
	byStructure		hasDesignMethod
	byFunction		hasDesignTip
Procedure Relations	cause		hasDesignResult
	justEarlierThan		hasDesignProcess
	justLaterThan		……

2) Data Properties.

A class has some descriptive properties which can be expressed through data properties. Data properties in product design ontology include: structure specifications, document specifications, diagram specifications, formula specifications, material properties, and value boundaries etc. Some data properties are given in Table 3.

TABLE 3: Some Non-Hierarchy Relations

engTerm	*principlePicID*	*hasPurpose*	*parameterSign*
has(dis)Advantage	*structurePicID*	*hasExplanation*	*largerThan/lessThan*
hasDefinition	*3DPicID*	*material*	*hasValue*
hasPrinciple	*formulaID/Note/Name*	*materialProperty*	*valueOption*
hasEffect	*unitName/Sign*		

FBS-based Ontology Modeling

In FBS model, connections between functions, behaviors, and structures are built by mappings. FBS model is an integrity of function model, behavior model, and structure model [9]. Structure model includes: components, types, material, and views; behavior model includes sub-behaviors, behavior-relations, behavior types, behavior-related components, and behavior-related input/output streams; function model includes: function aims, sub-functions, function types, meta-functions, objective functions, function-related components, and function-related input/output streams.

In this paper, for domain ontology, we focus on the structure model which corresponds to descriptive knowledge and individual knowledge in knowledge classification. Design ontology is formalized as function model and behavior model in FBS model. It corresponds to descriptive knowledge, procedure knowledge, manual knowledge, design guide knowledge, and individual knowledge. We firstly design function model in design ontology. Then, design behaviors are guided by functions which we want to implement. Our function model is consisted of documental design guides such as: main design tasks (includes several sub-tasks), notices, and design principles etc. Behavior model includes concrete design processes such as: design behaviors, design procedures, design formulae, design parameters, and design input/output etc.

1) Domain Ontology Modeling.

Before we define design ontology, we need to develop domain ontology. Domain ontology corresponds to structure model in FBS model. It also corresponds to descriptive knowledge and individual knowledge in knowledge classification. It includes concrete descriptive knowledge such as: classifications in design domain, constitutions of components, concrete individuals, material, definitions, disadvantages and advantages, principles, functions, experiences, and limitations etc.

2) Design Ontology Modeling.

We start from the main design task which is divided into several sub-tasks. Design guides are task-driven. They are consisted of design guide knowledge such as design notices, principles, indexes, and requirements etc. Design procedures are guided by design guide knowledge. Every process includes information about input/output, design methods, design formulae, design diagrams, related-people, and tools etc. Outputs of design procedures are design results. The model is shown in Figure 2.

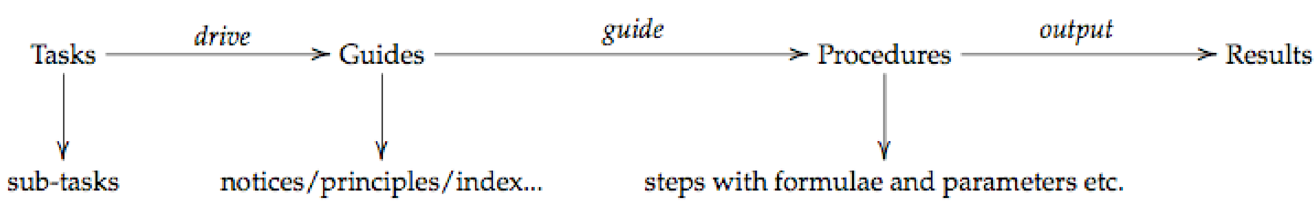

FIGURE 2: Product Design Ontology Modeling

CONSTRUCTION AND IMPLEMENTATION OF PRODUCT DESIGN ONTOLOGY

Construction Method of Product Design Ontology

The popular seven-step method proposed by Stanford University is not completely suitable for practical construction of product design ontology. Thus, based on seven-step method, we propose a new construction method for product design ontology.

1) Decide scopes and aims of construction of product design ontology: using analysis method of ontology system ability, we decide related domains of product design ontology. We do primitive analysis on questions which this ontology can answer and decide applicative requirements.

2) Decide semantic descriptive framework: we use top ontology in SUMO as basis.

3) Decide knowledge to express and define knowledge hierarchy structure: knowledge we want to express is composed of domain knowledge such as compositions, classifications, individuals,

applications, principles, advantages and disadvantages etc. and product design knowledge such as design tasks, design guides, design procedures, formulae, diagrams etc. We organize them into a hierarchy structure following top-to-bottom sequences such that the structure is defined by subclass relations.

4) Define object properties with their aspects: we define them from four angles: intrinsic properties, external properties, physical and abstract properties of components, and structural properties for connections between components. Also, we define characteristics and constraints to enhance abilities of semantic representation and reasoning in product design ontology.

5) Define hierarchy and non-hierarchy relations for objects: according to structures and classifications of product with its components, we define *subClassOf* and *isPartOf* hierarchy relations. According to compositions and structural connections of product with its components, we define synonymy relations, antonymy relations, metonymy relations, cause-effect relations, and propositional relations etc.

6) Define individuals: concrete products, types of components, and well-known design procedures are defined. Meanwhile, specific formulae and design parameters with their calculations are associated.

Construction and Implementation of Domain Ontology

In order to construct domain ontology for product design, firstly, we need to decide components with their sub-components which we want to describe; then, we need to define classifications of the above components and sub-components with their descriptive knowledge such as principles, functions, definitions, limitations, applications, material, positions, geometric structures etc.; finally, individuals of components and sub-components are added.

1) Classification knowledge of components is constructed as classes and subclasses while different classification standards are added as object properties for construction of connections between components and component types.

2) Concrete components with their sub-components are organized as parallel classes. The relations between components and sub-components are formalized as part-whole relations. Notice that *allValuesFrom* and *someValuesFrom* are different when the part-whole relation is used.

3) Define descriptive knowledge such as functions, principles, limitations, advantages and disadvantages, and applications etc. Define data properties with their values for classes and individuals.

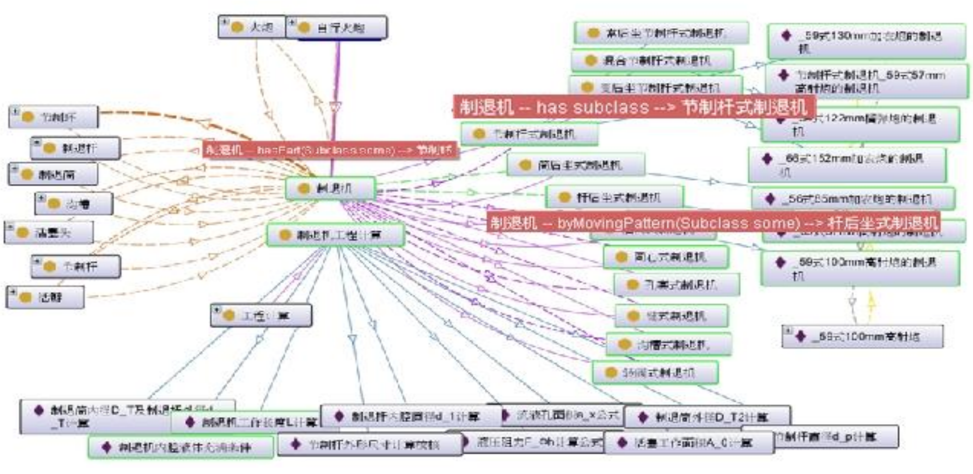

FIGURE 3: An Example of XXX Product Domain Ontology

4) Add individuals into components and sub-components. Check completeness and soundness of ontology construction by individuals.

Based on above methods, our implementation of construction of XXX product design domain in Protégé is given in Figure 3.

Construction and Implementation of Design Ontology

For our convenience of organization and construction of design ontology, we divide our design ontology into five classes: main task design, documental design experiences for design guides, design parameters and formulae, design diagrams, and design procedures with associated value boundaries.

1) Main Task Design.

Knowledge about main task design denotes tasks and aims in product design. It is motivation of whole design process. Hence, the first step of construction of design ontology is to decide main design tasks and design requirements of component design. Then, design guides and procedures are guided by tasks and requirements. They are represented as classes and sub-classes and are connected by *hasDesign-Task* relations.

2) Documental Design Experiences for Design Guides.

Design guide knowledge concerns about concrete guides driven by main design tasks. Documental design experiences for design guides include design notices, principles, requirements, and adjustments etc. They can be recorded in documents. New classes for design principles and requirements etc. are added. Properties about experience data with their values are added as well. Through object properties, documental design experiences and their corresponding component classes are connected.

3) Design Parameters and Formulae.

The main idea of construction in Protégé of parameters and formulae is: construct formula classes and add properties for formulae. But, concrete formulae with their inputs, outputs, and limitations etc. are added as associated contents into individuals.

4) Design Diagrams.

Design diagrams in product design mainly include 3D design pictures, components or whole individual pictures, principle diagrams for operational explanations, structure diagrams for positional relations, and flow charts for design procedures. Concrete pictures are stored in knowledge databases. In Protégé, they are added into classes and individuals as picture IDs.

5) Design Procedures with Associated Value Boundaries.

Firstly, we construct classes for design procedures and connect them with component classes by the *hasDesignProcess* relation. Concrete design procedures are added as subclasses. The ordering of procedures is represented by time-sequence relations and cause-effect relations between object properties. Properties such as procedure explanations, experiences, tools, related formulae and pictures and results etc. are added.

Then, we construct classes for design parameters. They are connected to object properties and design procedures by *hasInputParameter* and *hasOutputParameter* relations. For each parameter, we associate it with values, upper bounds, lower bounds, and options.

Based on above ontology construct method, our implementation of construction of XXX product design ontology in Protégé is given in Figure 4.

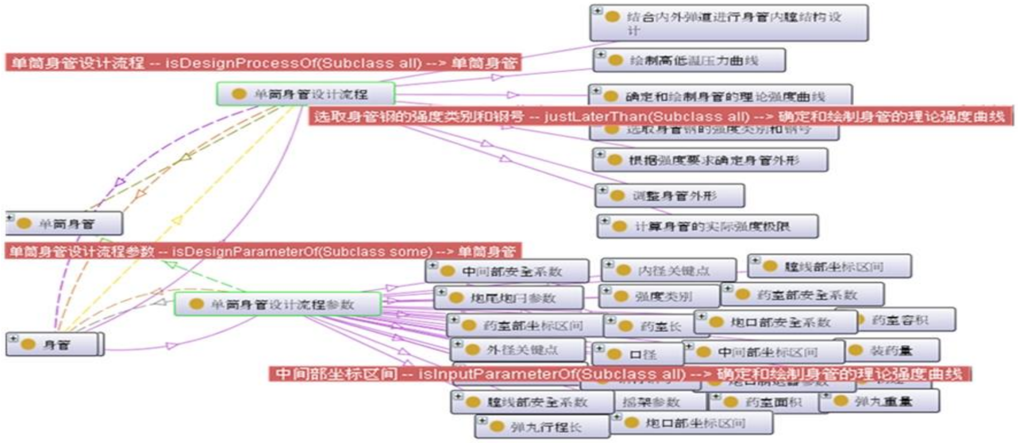

FIGURE 4: An Example of XXX Product Design Ontology

CONCLUSIONS

Construction of product design ontology is vital to solve the problem of knowledge sharing. With growth of OWL, its supporting tools, and its applications, based on FBS-model, the construction method of domain ontology and design ontology towards product design with modified seven-step construction method proposed in this paper, will be one of effective methods, from the view of knowledge, to reuse and share knowledge for product design.

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