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Collaborative Design System based on Object-Oriented Modeling of Supply Chain Simulation: A Case Study of Thai Jewelry Industry

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***Abstract*—**The paper proposes a new concept in developing collaborative design system. The concept framework involves applying simulation of supply chain management to collaborative design called – '*SCM–Based Design Tool*'. The system is developed particularly to support design activities and to integrate all facilities together. The system is aimed to increase design productivity and creativity. Therefore, designers and customers can collaborate by the system since conceptual design. *JAG: Jewelry Art Generator* based on artificial intelligence techniques is integrated into the system. Moreover, the proposed system can support users as decision tool and data propagation. The system covers since raw material supply until product delivery. Data management and sharing information are visually supported to designers and customers via user interface. The system is developed on Web–assisted product development environment. The prototype system is presented for Thai jewelry industry as a system prototype demonstration, but applicable for other industry.

***Keywords*—**Collaborative design, evolutionary art, jewelry design, supply chain management.

I. Introduction

NOWADAYS Thai Gems and Jewelry Industry (TGJI) employs over one million workers in more than 800 companies, gains 130 billion Baht in the year 2006. TGJI has high potential in growing in the world market. To increase the potential in competitiveness, one of the most important issues that should be considered is "How to satisfy customers with the attractive designs in the short time?" We have found one important bottleneck in Thai jewelry industry, which appears in the design and model-making processes [1]. Jewelry designers deal with several considerations such as jewelry styles, customer classes, jewelry types, casting materials, gem types, and gem size, in order to balance beauty and functions of products. Creative design typically depends on knowledge, experiences, and perceptions of designers. Meanwhile, they consider and evaluate their designs in term of material used and manufacturing possibilities.

Supply chain management (SCM) has developed to offer more effective methodologies for various industries and businesses. SCM is a collaborative effort that combines many parties or processes in product life cycle from the use of raw materials to the stage that consumer purchases product.

Therefore, the goal of this research is to analyze and identify the fundamental elements or objects that are necessary for modeling supply chain framework used in collaborative design and manufacturing. The resulting analyses is to develop a SCM-based design tool integrated with an intelligence design system using in collaborative design and manufacturing to support jewelry designers' activities and to increase efficiency in jewelry design and manufacturing.

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II. Literature Review

A. Supply Chain Management

Several definitions of supply chain and SCM are presented by researchers and practitioners from various points of views. This paper summarizes here in the general concept of them, which can be applied to work in collaborative design and manufacturing.

Supply chain is a network of enterprises linking flows since raw material supply to final products and interacting to deliver/distribute products or services to end customers [2]. Other research defines the supply chain in the same context see in [3]. A streamlined SCM is the network of facilities and distribution options to support an association of vendors, suppliers, manufacturers, distributors, retailers, and other trading partners. Effective management of supply chain systems can be achieved by identifying customer service requirements, determining inventory placement and levels, and creating effective policies and procedures for the coordination of supply chain activities. The coordination of logistics functions into the integrated supply chain systems has increased the need for improving the process quality.

Improving the quality of all supply chain processes results in reduced utilization, and improved process efficiency [4].

Enterprise Resource Planning (ERP) is technologically said to be the backbone of SCM, because they both rely on very similar framework, such as intranet, extranet and electronic data interchange [5].

Rezayat propose the Enterprise-Web portal for life-cycle support, which enables integrated product, process, and protocols development [6]. He suggests Web-based electronic access to design and manufacturing information within the extended enterprise based on its universal interface, open standards, ease of use, and ubiquity. He recommends combining the distributed object standards with the Web standards and protocols to create the Object Web. He proposes combining the Object Web with an enterprise's information authoring, and management systems to create the Enterprise-Web portal.

Rossetti and Chan present the design, development and testing of a prototype object-oriented framework for performing supply chain simulations [7]. They define the primary objects required for supply chain simulations and designs how each of these objects are related to each other to form a supply chain network. They also discuss how persistence is handled for instantiating supply chain network simulations from a database.

Xiang, Chen and Havens present a collaborative design networks to represent collaborative design knowledge as multi-agent graphical models [8]. They propose a set of algorithms that allow agents to produce an overall optimal design by autonomous local evaluation of local designs. These algorithms can reduce the complexity exponentially from that of an exhaustive centralized design.

The web-based part library used in collaborative design, concurrent engineering, virtual enterprise and supply chain management system is developed [9]. The part library is integrated into CAD systems to share part/product data and information among enterprises. Thus it is necessary to develop system under standard data and systems.

A generic methodology to design production-distribution network of divergent process industry companies in multinational context is presented [10]. In this research, a mathematical programming model for mapping the industry manufacturing process onto potential production-distribution facility locations and capacity options is developed. A directed multi-graph of production and storage activities is applied to represent the industrial process. Associating One-to-many recipes to production activities is to model the divergent nature of the process. The divergent nature of the process is modeled by associating one-to-many recipes to each of its production activities. The manufacturing process is mapped onto the potential network nodes. The methodology is illustrated by applying it to the case of the softwood lumber industry.

B. Expert System

The successes of expert system (ES) appear in various researches, some of them are briefly described as follows.

An agent-based framework is applied to develop an expert system for concurrent product design and planning for assembly [11]. This intelligent system provides systematic assistance for assembly design and planning in the early stage of product development. Shelab and Abdalla present an intelligent knowledge-based system for modeling product cost [12]. They apply hybrid knowledge representation techniques such as production rules, frame, and object–oriented, to represent manufacturing knowledge. Fuzzy logic-based knowledge representation is applied to deal with uncertainty in the knowledge of cost model to generate reliable cost estimation.

CBR methods applied in an expert system for aided design during the ship design process are introduced [13]. CBR is used for solving problems related to databases and knowledge bases. The adaptation of solutions is the main concept in generating new design solutions. The calculation of ship's similarity verified by fuzzy logic is used to search the existing cases in database.

An expert system is proposed as a solution to the empirical, heuristic and subjective nature of current art psychotherapy methods [14]. The framework of the expert system and its design, knowledge acquisition, representation methods, and modeling of human reasoning process of diagnosis are presented. The user interface is developed to assist non-experts to use the system.

Other application of expert system is presented in [15]. Customer requirement information system (CRIS) for machine tool manufacturers is developed based on the integration of rule-based fuzzy inference and expert systems. The proposed CRIS is used to support both customers and service personnel in providing a systematic way of fulfilling and analyzing customer requirements. The fuzzy inference is adopted to articulate the unclear parts of requirement wordings. CRIS applies expert systems to infer the root causes of problems and to advise an appropriate solution to those problems.

A computer-based design system that links between CAD tool and designer is developed, based on expert system and case-based reasoning (CBR) [1]. However, the mentioned tool still has limitations in jewelry design database and variety of jewelry designs. It depends on the development of knowledge base.

C. Evolutionary Art and Design

One of the possible ways for solving ES limitations is based on evolutionary design process. Evolutionary art and design system is an effective way to create attractive pieces of art, which possess very distinct styles but mostly non-functional. In evolutionary art system, evolutionary process works as a form generator by providing varieties of forms rather than an optimizer. As a result, designers can explore more design alternatives. During evolutionary process, the fitness functions that quantify aesthetics can be done by human evaluator or the

developed software. In addition, the evolutionary process should continuously generate the new art forms based on the individuals' fitnesses from the previous generations. This can take advantage of evolution and form growth to improvement of shape generation.

There have been several researches in these areas, which are used in the creations of artistic forms and design applications, see examples in [16]-[26].

Wannarumon and Bohez propose a new evolutionary design approach to create the non-functional art forms for jewelry design [27]. The improvement of EA approach and the enhancement of the algorithmic aesthetics are presented in [28]. In this work, interactive evolutionary design system is proposed for user-centered jewelry design – *JAG*: Jewelry Art Generator. Art forms are modeled by using fractal geometry known as iterated function system (IFS).

The major elements in evolutionary algorithms in art and design are genotype, phenotype, genetic operator, fitness function and selection. The details of these elements can be found in [17].

Most of evolutionary art and design systems generate new forms based on the random initial populations. Each individual of population can be evaluated for its fitness by human artists or computers. Often, population size is less than ten individuals [17], which are then judged rapidly in each generation. User interfaces are usually designed to facilitate users to easily evaluate individuals' fitnesses, rank or select individuals.

III. Frame Work of SCM-Based Design Tool

A. System Architecture: Overview

The main objective of this research is to develop a robust supply chain management system, which results the efficient, easy to maintain and reliable application. Therefore, the approach to construct the collaborative design and manufacturing network is based on Object-Oriented Modeling (OOM) [29], which represents the system domain down to the object level. The Object-Oriented System (OOS) is composed of several objects in several levels; and these objects have relationships and interactions with other objects. The hierarchy of objects is built by organizing the OOS by classes. The Unified Modeling Language (UML) is a set of OOM notations standardized by the Object Management Group [30]. UML enables to depict the supply chain system like as a particular domain in OOM.

The system is created based on Web platform to support communications, collaborations and sharing data/information among users in the supply chain. The activities within the framework are viewed as dynamic actions that make up as a dynamic system. In the enterprise, the facilities are integrated with PDM/ERP packages. The enterprise is extended to outside clients by supply chain management concepts. These are to construct the collaborative environments. CAD and PDM systems are utilized in the design stage, where designer and customer collaborate to achieve the desire solutions via Web support. The Web-based integration of collaborative design and manufacturing network is shown in Fig.1 and its system architecture is illustrated and Fig. 2.

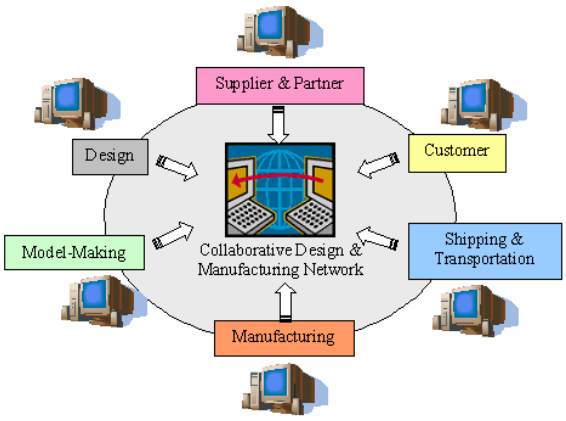

Fig. 1 Web-based integration for collaborative design & extended enterprise network space

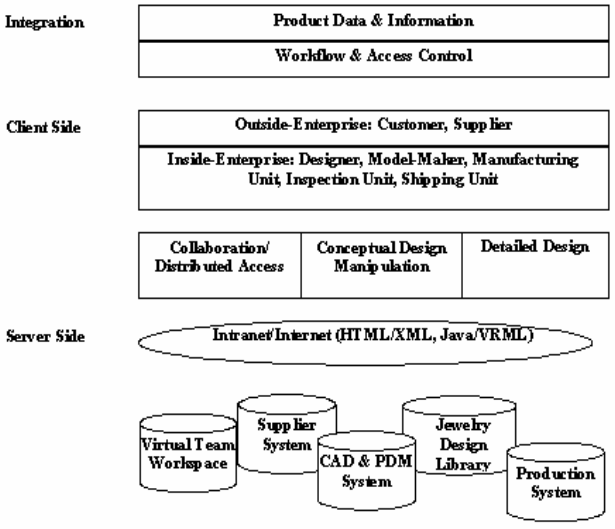

Fig. 2 System architecture of collaborative design & manufacturing system

Data repository is accessed and utilized by inside and outside clients. The data flow at work is dynamic to fulfill decision making and to propagate to the requests. The Web-based tool provides secure, reliability and easy-to-access, and multiple access methods.

B. Object-Oriented Modeling: A Prototype

Design and manufacturing processes are analyzed and classified to present classes within the supply chain network. In our framework, it consists of 24 classes, which are set up based on their attributes and operation, see Table I.

TABLE I
LIST OF CLASSES IN SCM-BASED DESIGN TOOL FRAMEWORK

No.	Class Name	No.	Class Name
1	CADSystem	13	Material
2	Customer	14	Model-Maker
3	Designer	15	Model-MakingUnit
4	DesignSystem	16	Node
5	InspectionUnit	17	Order
6	Inventory	18	OrderGenerator
7	JewelryArtGenerator	19	PackagingUnit
8	JewelryProduct	20	Relationship
9	JewelryStyle	21	RelationshipNetwork
10	JewelryType	22	Shipping
11	Location	23	Supplier
12	ManufacturingUnit	24	WarehouseCenter

There exist 7 classes that represent the facilities within the supply chain simulation framework: CADSystem, DesignSystem, InspectionUnit, ManufacturingUnit, Model-MakingUnit, PackagingUnit, and WarehouseCenter. The major roles of facilities are supporting services, manufacturing products, distributing and delivering products/services to customers. RelationshipNetwork is degned as as a complex system that represents the interconnected network nodes. Such nodes exchange and share data and information. They also carry on materials and work-in-process through the facilities until finishing the products and shipping. A Relationship connects 2 nodes and specifies the possible flow of information between them. A Node represents a facility in the framework. Customer, Designer, Model-Maker, and Supplier are classified as actors in the supply chain framework.

The object-oriented model is subdivided into 3 sub-models, which assemble into the entire picture of framework. The UML sequence diagram is employed to illustrate the flow of data, information, material and WIP along the entire framework.

1) Designer – Customer Interaction

In this research, DesignSystem is utilized to act as a center that communicates with other associating facilities. Firstly, it is introduction of the UML sequence diagram of Designer–Customer Interaction (see Fig. 3) that represents the flow of order and design information since customer interacts with the enterprise's system via DesignSystem. In this stage, customers can communicate what they preferences are. Designer can assist customers to sketch their ideas on the electronic board through assisting of *JAG* Jewelry Art Generator, which was developed by Wannarumon and Bohez [28], and CADSystem. The end of this session results the final design that is ready to produce, Bill of Material (BOM), the order confirmation from customer. Then the resulting design is sent to the next stage to make its model.

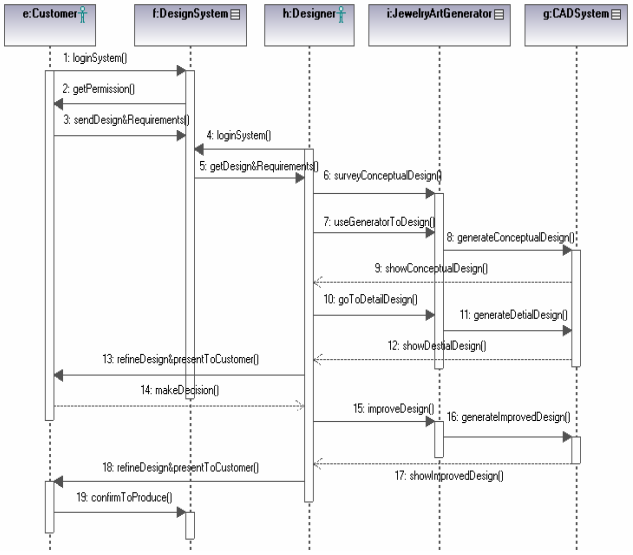

Fig. 3 UML sequence diagram of designer–customer interaction

2) Design System–Associating Inside Enterprise Facility Interactions

The customer-based design with the generated order information are concurrently initialized the second and third sub-models, see Fig. 4. In the second sub-model, the jewelry model is made by a model-maker. The model may be made from wax, silver, copper or brass. The production order and

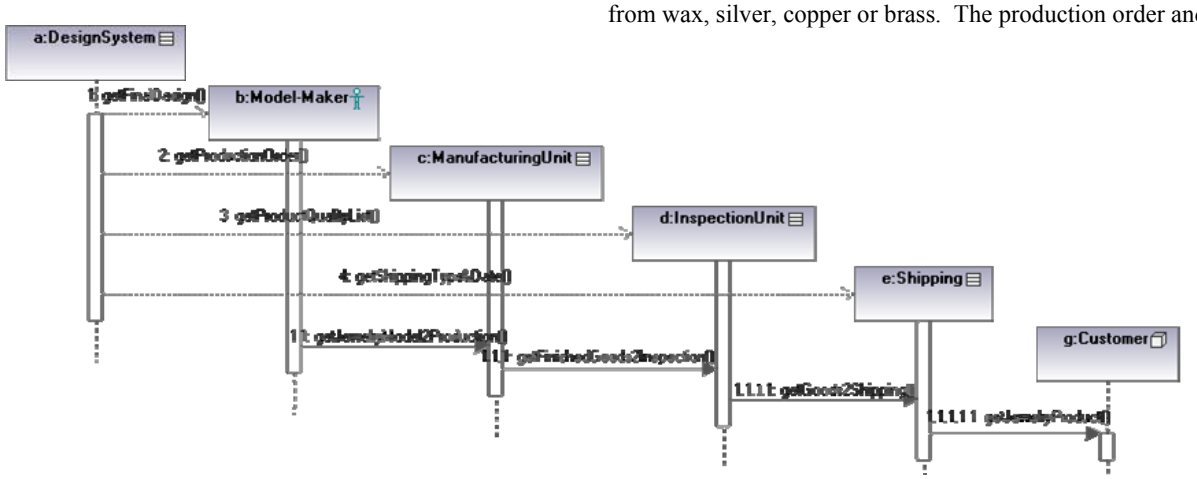

Fig.4 UML sequence diagram of design system – associating inside enterprise facility interactions

the model are launched to the ManufacturingUnit to produce the jewelry products. After finishing production, the products are inspected following the customer requirement quality level. The qualified product are packed and shipped/ delivered to customer.

3) Design System–Outside Enterprise Facility Interactions

The third sub-model consists of two interconnections: suppliers and customer, to confirm the raw material and order, see Fig. 5. BOM is generated by DesignSystem, Model-Making and ManufacturingUnit and then sent to Supplier. Supplier sends the feedback to the system to confirm delivery of the required materials. The system estimates the production lead time and confirm the due date to Customer.

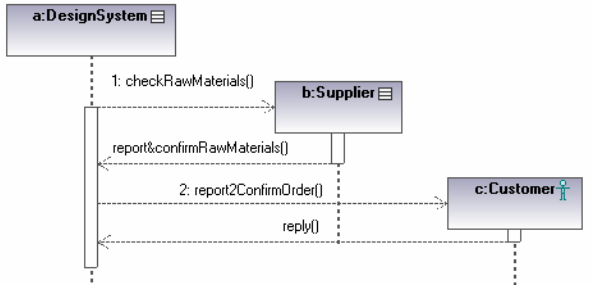

Fig. 5 UML sequence diagram of design system – outside enterprise facility interactions

IV. Collaborative Design Engine

The concepts of expert system and evolutionary algorithm are applied to outline the approach for generating jewelry art forms. Our design system – '*JAG: Jewelry Art Generator*' is aimed to increase both diversity and productivity of art forms during jewelry design process. The design engine architecture is illustrated in Fig. 6.

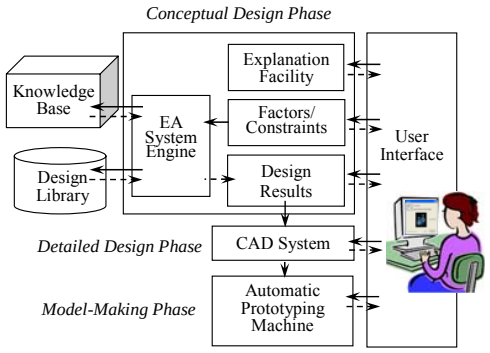

Fig. 6 *JAG: Jewelry Art G*enerator's system architecture

JAG is placed in the CAD system stage, which designers and customers can use in the design process via a user interface.

The proposed algorithmic design consists of '*designer interface*', which supports designers to easily collaborate with the system and input their ideas and styles into the system; '*design generating algorithm*', which derived from EA and ES, the design generating algorithm is used for creating new design alternatives regarding to the designer's preferences and styles; '*design evaluating algorithm*' for quantifying the morphology and aesthetics of art forms; '*automatic model making*' that is a linkage between jewelry design to model-making stage, it connects the design system *JAG* to the computer numerical controlled (CNC) machine and rapid prototyping (RP) machine for manufacturing jewelry hard models directly from the design stage, these jewelry models are further used in production process. More details of *JAG* can be found in [28].

V. Results and Discussions

A. Development of Web-Based Design Tool

The Web-based system can be constructed in many ways depending on the user requirements and construction difficulties. Under our system architecture, the prototype is developed based on VRML, which is the Internet standard for communicating rich 3D data. VRML provides rich capacities in interaction, navigation, and hyperlink to multimedia and HTML files. The Web-based design tool is considered as a future trend in product development at the extended enterprise level.

Due to well-defined semantics, UML is selected to assist to model the framework of Object-Oriented Supply Chain Simulation for collaborative design. UML provides a clarified spectrum of notations for representing different aspects of the system.

At the extended enterprise level, customers and suppliers can easily connect and interact with the enterprise. The inside-enterprise users also can connect to other users concurrently throughout the development cycle. These activities need Knowledge-Based product development to act as a backbone of the system.

B. Collaborative Design System

The proposed design system facilitates designers to easily generate the initial sketches of designs based on their preferences and signatures. It also helps in communication among the design team. The system assists an enterprise to integrate the raw material preparation, design, model-making, manufacturing, quality control, and shipping stages. Therefore, the design system can support concurrent works and shorten time in process.

The mechanisms that drive the system to generate and evaluate the jewelry designs are hidden under the designer interface. The designer interface is the outer shell that a designer can communicate and collaborate with the system via the user-friendly interactions. *JAG: Jewelry Art Generator* opens for jewelry designers and customers to create new jewelry ring designs by various methods.

Designers can start their designs by providing customer requirements and design requirements such as general geometric-shape attributes and material used to the system.

For the geometric shapes, the symmetrical shapes are such as mirror symmetry, rotational symmetry, logarithmic spiral symmetry, others are asymmetrical shapes, complex shapes, and simple shapes. For example, if a designer favors on the symmetrical shapes, and selected the type of symmetry as logarithmic spiral, and also the complex shapes, then the system automatically generates a set of new jewelry ring designs. As well as he can explore other sets of alternatives.

The system offers designers to link to CAD system, and then they can modify the favorite design using CAD software. Designers can collect the resulting jewelry ring design in their own design libraries, and make hard prototypes of the design directly by CNC milling or RP machine.

VI. Conclusion and Future Works

In this research, SCM play the key role to link design stage to the other stages in the entire process including customers and suppliers. The prototype is developed based on Object-Oriented Modeling by using the Unified Modeling Language. The primary entities required for supply chain simulations is represented via UML use case diagrams and sequence diagram for illustrating relationships and interactions among these entities and for describing the flow of activities in the entire process. The results indicate that the framework can easily model the simple circumstances. This simple scenario can be easily expanded to include multiple products and multi echelons. *JAG: Jewelry ART Generator* based on ES and EA is integrated into the SCM-based design tool for supporting the design activities. The proposed system can reduce processing time in design and manufacturing. This SCM-based design tool then can be viewed as one of the solvers in the design bottleneck.

For further work, the system prototype is being developed with greater details to simulate the framework closer to the real scenario. The efficiency of the simulation will be increased by using multi-agent concept. The improvement of design-evaluating algorithm in *JAG* involves manufacturability, designer's individual style, and color.

References

[1] S. Wannarumon, K. Unnanon, and E. L. J. Bohez., "Intelligent computer system for jewelry design support", *Computer-Aided Design & Applications*, vol.1, nos. 1-4, pp. 551-558, 2004.

[2] L. M. Ellram, "Supply chain management: The industrial organization perspective", *International Journal of Physical Distribution and Logistics Management*, vol. 21, no. 1, pp. 13–22, 1991.

[3] K. C. Tan, "A framework of supply chain management literature", *European Journal of Purchasing & Supply Management*, July, pp. 39-48, 2001.

[4] A. Dawson, "Supply chain technology", *Work Study*, vol. 51, no. 4, pp. 191–196, 2002.

[5] J. M. Tarn, D. C. Yen, and M. Beaumont, "Exploring the rationales for ERP and SCM integration", *Industrial Management & Data Systems*, vol.102, no.1, pp. 26-34, 2002.

[6] M. Rezayat, "Enterprise-Web portal for life cycle", *CAD Computer Aided Design*, vol. 32, no. 2, pp. 85–96, 2000.

[7] D. Rossetti and H.-T. Chan, "A prototype object-oriented supply chain simulation framework", in *Proceedings of the 2003 Winter Simulation Conference, S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, eds.*, pp. 1612–1620, 2003.

[8] Y. Xiang, J. Chen, W. S. Havens, "Optimal design in collaborative design network", in *AAMAS'05* Netherlands, pp. 241–248, 2005.

[9] Y. Li, Y. Lu, W. Liao, and Z. Lin, "Representation and share of part feature information in web-based parts library", *Expert Systems with Applications*, vol.31, no. 4, pp. 697–704, 2006.

[10] D. Vila, A. Martel and R. Beauregard, "Designing logistics networks in divergent process industries: a methodology and its application to the lumber industry", *Int. J. Production Economics*, vol.102, pp. 358–378, 2006.

[11] X. F. Zha, Y. E. Lim, and S. C. Fok, "Development of expert system for concurrent product design and planning for assembly", *The Int. J. of Advanced Manufacturing Technology*, vol.15, pp. 153-162, 1999.

[12] E. Shehab and H. Abdalla, "An intelligent knowledge-based system for product cost modeling", *Int. J. Advanced Manufacturing Technology,* vol. 19, pp. 49-65, 2002.

[13] Z. Kowalski, M. Meler-Kapcia, S. Zieliński and M. Drewka, "CBR methodology application in an expert system for aided design ship's engine room automation", *Expert Systems and Applications*, vol. 29, no. 2, pp. 256-263, 2005.

[14] S. -I. Kim, H. –J. Ryu, J. –O. Hwang and M. S. –H. Kim, "An expert system approach to art psychotherapy", *The Arts in Psychotherapy*, vol. 33, no. 1, pp. 59-75, 2006.

[15] Y. -S. Juang, S. –S. Lin and H. –P. Kao, "Design and implementation of a fuzzy inference system for supporting customer requirements", *Expert Systems and Applications*, vol. 32, no. 3, pp. 868-878, 2007.

[16] J. Gero, "Creativity, emergence and evolution in design: concepts and framework", *Knowledge-Based Systems*, vol. 9 no. 7, pp. 435-448, 1996.

[17] P. Bentley, *Evolutionary design by computers*, San Francisco: Morgan Kaufmann Publishers, 1999.

[18] C. Eckert, I. Kelly and M. Stacey, "Interactive generative systems for conceptual design: an empirical perspective", *Artificial Intelligence for Engineering Design, Analysis and Manufacturing,* vol. 13, no. 4, pp. 303-320, 1999.

[19] A. Rowbottom, "Evolutionary art and form", in *Evolutionary Design by Computer*s (Bentley, P., Ed.), pp 261-278. San Francisco, CA: Morgan Kaufman, 1999.

[20] D. Rowland and F. Biocca, "Evolutionary co-operative design between human and computer: implementation of the genetic sculpture park", in *Proc. 5th Symp. on Virtual Reality Modeling Language (Web3d-Vrml), VRML '00*, pp. 75-79. New York: ACM Press, 2000.

[21] S. Rooke, "Evolutionary art", in *Creative Evolutionary Systems* (Bentley, P.L., & Corne, D.W., Eds.), pp. 337-365. San Francisco, CA: Morgan Kaufmann, 2000.

[22] D. Grundler and T. Rolich, "Evolutionary algorithms aided textile design", *International Journal of Clothing Science and Technology,* vol. 15, no. 3-4**,** pp. 295-304, 2003.

[23] K. Wloch and P. J. Bentley, "Optimising the performace of a formula one car using a genetic algorithm", *Genetic and Evolutionary Computation Conference (GECCO 2004).* Seattle, Washington, June 26-30, 2004.

[24] K. Bentley, E. J. Cox and P. Bentley, "Nature's batik: a computer evolution model of diatom valve morphogenesis", *Journal of Nanoscience and Nanotechnology*, vol. 5, no. 1, pp. 1-10, 2005.

[25] K. Koile, "Formalizing abstract characteristics of style", *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 20, no. 3, pp. 267-285, 2006.

[26] E. Poirson, P. Dépincé, and J. –F. Petiot, "User-centered design by genetic algorithms: application to brass musical instrument optimization", *Engineering Applications of Artificial Intelligence,* vol. 20, no. 4, pp. 511-518, 2006.

[27] S. Wannarumon and E. L. J. Bohez, "A new aesthetic evolutionary approach for jewelry design", *Computer-Aided Design & Applications*, vol. 3, no. 1-4, pp. 385-394, 2006.

[28] S. Wannarumon and E. L. J. Bohez, "Jewelry Art Generator: automatic computer-aided design", in Proc. of the 7th Asia Pacific Industrial Engineering and Management Systems Conference (APIEMS'06), Bangkok, Thailand, pp.2361-2368, 2006.

[29] B. Bruegge and A. H. Dutoit, *Object-Oriented Software Engineering*, New Jersey: Prentice-Hall, 2000.

[30] R. France, A. Evans and K. Lano, "The UML as a formal modeling notation", in *Proc. OOPSLA'97 Workshop on Object-oriented Behavioral Semantics*, H. Kilov, B. Rumpe and I. Simmonds (eds.), pp. 75–81, 1997.

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