INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

EVALUATION OF A CONTEXT KNOWLEDGE BASED TOOL TO SUPPORT DECISION MAKING IN CONCEPTUAL DESIGN

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ABSTRACT

Selecting design concepts while exploring their solution space makes conceptual design a decision intensive process. Due to the complex nature of conceptual design, decisions taken by designer at the conceptual design stage play an important role in all subsequent phases of product life cycle, the user satisfaction of the product and the environment that the product is used and disposed of. Reviews of existing methodologies reveal that there is a need for designers to have a holistic understanding of and access to total context knowledge of the design problem under consideration to aid their decision making at the conceptual design stage. The design solution space could be explored effectively and an optimal solution could be generated if this knowledge is properly structured and available to use for the designers at the conceptual design stage. A new research approach addresses this problem by proposing, implementing and evaluating a computational framework for supporting decision making at the conceptual design stage using design context knowledge. The evaluation of the implemented tool in this paper shows that the method is effective in proactively supporting the designer's decision making using design context knowledge as a new and holistic approach. The scale up of the approach remains a challenge.

Keywords: Context Knowledge, Conceptual Design, Decision Making

1 INTRODUCTION

Decisions made during conceptual design have significant influence on the cost, performance, reliability, safety and environmental impact of a product. Studies conducted by some researchers [1, 2] indicate that as much as 75% of the cost of a product is being committed during the design phase. It is therefore, vital that designers have access to the right tools to support such design activities. In the early 1980s, researchers began to realize the impact of design decisions on downstream activities, as a result of which different methodologies such as design for assembly, design for manufacturing and concurrent engineering, have been proposed. While software tools that implement these methodologies have been developed, most of these are applicable only in the detailed design phase. However it is critical to understand that even the highest standard of detailed design cannot compensate for a poor design concept formulated at the conceptual design phase. This research aims to understand the implications of design decisions on other life cycle stages of the product and develop tools to provide support to decision making at the conceptual design stage through background reasoning of design context knowledge. This is accomplished by using the whole *context* of the design problem based on the characterization and formalization of the *Design Context Knowledge* into different groups and context knowledge categories [3]. This research addresses this problem by proposing, implementing and evaluating a computational framework [4] for supporting decision making at the conceptual design stage using design context knowledge. This paper presents briefly the methodology behind the computational framework. It also describes the system architecture, development, working of prototype system by doing a case study of a sheet metal component conceptual design problem and mainly the evaluation of the system in order to show the selection of conceptual design solutions satisfying not only functional requirements but also catering for different implications/constraints by generating potential good/problematic consequences.

2 CONCEPTUAL DESIGN DECISION MAKING

The design concept selection done while exploring solution space makes the conceptual design stage a decision intensive process [5, 6, 7]. Decisions are made on various aspects of the product being designed [8] and typical decisions involve selection of working principles and corresponding concepts and solutions. Furthermore some decisions, which seem appropriate for one life cycle requirement, can pose problems on other life cycle phases [9]. This implies that the part of a decision taken within one life phase (e.g. product design) affects the type, content, efficiency and progress of activities within other life phases (e.g. assembly, manufacturing, use). For example a small decision of using countersink head screws instead of snap fit to assemble two parts will result in different design, manufacture and maintenance approaches and techniques. Therefore designers need to be aware of consequences of their decisions early at the conceptual design stage to perform an effective and informed life cycle oriented decision making.

2.1 Decision consequences' awareness

Design decisions are associated with consequences [10, 11] which can either be intended or unintended and both good or problematic [12] and have the ability to influence the performance of other life-cycle phases in terms of measures such as cost and time [9]. Gero [13] argues that the conceptual design process is a sequence of situated acts. He calls this concept situatedness i.e. the notion that addresses the role of the context knowledge in engineering design. This implies that conceptual design is a dynamic activity, which should be undertaken in the context of external world and therefore any decisions made by the designer have implications on the external world comprising, which comprises environment of the product and users of the product. It is therefore necessary for the designers to be aware of the consequences of their decisions made at the conceptual design stage not only on the later life phases of the product but also on the whole context of the design problem under consideration i.e. the external world, life phases, environment of the product, and users of the product. Therefore there is a need not only to identify the whole context or contextualised information/knowledge of design but also to formalise it in some structured form and present it for designer's consideration early during the synthesis stage of the design, i.e. when the decision making takes place at the conceptual design stage.

3 CONTEXT IN DESIGN

There are many uses for the word 'Context' in design, and information/knowledge described as 'Context' is also used in several ways. One dictionary [14] definition of context is *the set of facts or circumstances that surround a situation or event*. Charlton and Wallace [15] summarised design context interpreted by different researchers as follows:

- *"The life cycle issue(s), goal(s) or requirement (s) being addressed by the current part of the product development process: e.g. safety; usability; assembly.*
- *The function(s) currently being considered as an aspect of the product: e.g. transmitting a torque; acting as a pressure vessel.*
- *The physical surroundings with which a part of the product can interact, including either internal or external aspects of the product's environment; e.g. the components in a hydraulic system; the temperature of the operating environment; the manufacturing environment; aspect of the surrounding landscape reflected in an architectural design".*

To date few researchers have only provided a contextual framework to explore relationships between the design context and design practice giving no consideration to the impact of all context knowledge on decision making at the conceptual design stage. There is not a single work representing the holistic view of '*Context'* in design i.e. from other perspectives apart from these aspects, which is necessary to perform an effective decision making at the conceptual design stage. This research refers *'Context'* as a knowledge having information about surrounding factors and interactions which have an impact on the design and the behavior of the product and therefore the design decision making process which result in design solutions at a particular moment of time in consideration. Therefore the *Design Context Knowledge* is defined as *the related surrounding knowledge of a design problem at a given moment in time for consideration* [3].

3.1 Design context knowledge formalism

The review of existing methods and frameworks indicated that the lack of the consideration of design context knowledge and its implications during the decision making is due to the lack of understanding and non-availability of a proper formalism of the design context knowledge. Based on the adopted definition, this research has proposed and implemented a classification in order to structure the design context knowledge for a systematic use. The research formalizes design context knowledge in six different groups. These groups are *Life Cycle Group, User Related Group, General Product Related Group, Legislations & Standards Group, Company Policies and Current Working Knowledge* [16] (that is partial solution information generated up till current stage of the design process for a given problem). Design context knowledge formalised in first five groups is of static nature and it can be further classified into different categories of knowledge depending upon the nature of design problem and design domain under consideration so that it is easy to use this knowledge in decision making. However as first three groups are generic in mechanical design domain and can be used in any design organisation, therefore this research has classified these three groups in ten different categories of context knowledge [3]. This identification stems from the work done by the authors and other researchers in the areas of design synthesis for multi-X as well as product life cycle modelling [17, 18, 19]. The work [17, 18, 19] done earlier by authors illustrate the significance of generation of life cycle consequences on different life cycle phases (design, manufacturing, assembly, dispose) of product in the form of positive and negative implications due to the selection of a particular design solution. The work reported in this paper built further on previous work by not only considering consequences related to different life cycle phases but also consequences related to the user of product and the environment in which the product works/operates. Therefore a more holistic and wider view of design problem is considered by formalising design context knowledge into different categories and using them in supporting decision making at the conceptual design stage. It is noted that these categories of context knowledge are by no means exhaustive. There could be even more knowledge groups/categories that should be considered depending upon the nature of a design problem under consideration, however in metal component design particularly in sheet metal component design, these categories can be used to explore fully the knowledge important for consideration at the conceptual design stage. These categories are:-

1. User requirements/preferences
2. Product/Components' material properties
3. Quality of means/solution during use
4. Pre production requirement
5. Production requirement
6. Post production requirement
7. Production equipment requirement
8. Quantity of product required
9. Achievable production rate
10. Degree of available quality assurance techniques

The detail of these categories is out of the scope of this paper. These ten categories of context knowledge can be used for reasoning to provide decisions' consequences awareness to the designer at the conceptual design stage. The conceptual design process is often modelled as the transformation between three different information states [20] as function, behaviour and form of solution means framework explaining the interactions between these three elements, therefore this research proposes a new function to means mapping model, which used these ten categories of design context knowledge to support conceptual design decision making.

4 FUNCTION TO MEANS MAPPING MODEL

Conceptual design is a function to means mapping process, during which decision-making takes place regarding the selection and evaluation of design alternatives. This process involves deriving implementable functions by decomposing them into finer resolutions, identifying means to realise them and evaluating those means by reasoning using existing and new knowledge/information against evaluation criteria. A potential solution for *Convert Rotary Motion into Translatory motion* function could be a *Rack & Pinion Assembly.* Observing the product from the constructional point of view [21] results *in product breakdown structure (PBS).* Borg [19] presented this structure as a number of elements called *product design elements (PDE).*

4.1 Product design elements based conceptual design

A PDE at component building level is a reusable design information unit (element) representing a potential solution means for a function requirement. Of relevance to this definition and looking from the viewpoint of component construction, a more commonly used term *feature* is considered to be an information element defining a region of interest within a product. Using the above PDEs structure and focusing on metal component design, it can be seen that means of achieving a function are more likely manufacturing features as shown in figure 1; as five such possible manufacturing features presented as means to realize a Provide Semi-Permanent Assembly function. For a given functional requirement, PDEs are the information carriers that allow the mapping between function requirements and physical solutions of a product. In this research, PDEs are used as the basis of function based conceptual design [22], in which a design solution is generated from product function point of view, using available well-understood function-PDEs relationships to identify suitable means in the form of these Product Design Elements.

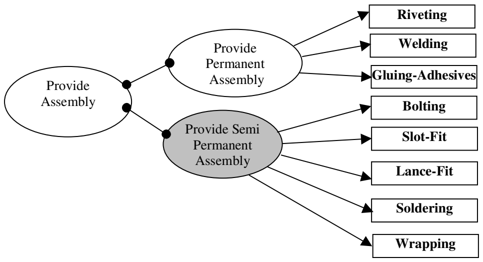


Figure 1. Function-Feature association

4.2 Design Context Knowledge Based Function to PDE Mapping Model

In order to support decision making at the conceptual design stage, a new generic function to PDE mapping process model is proposed here in this research [4], which uses design context knowledge to support decision making as shown in figure 2.

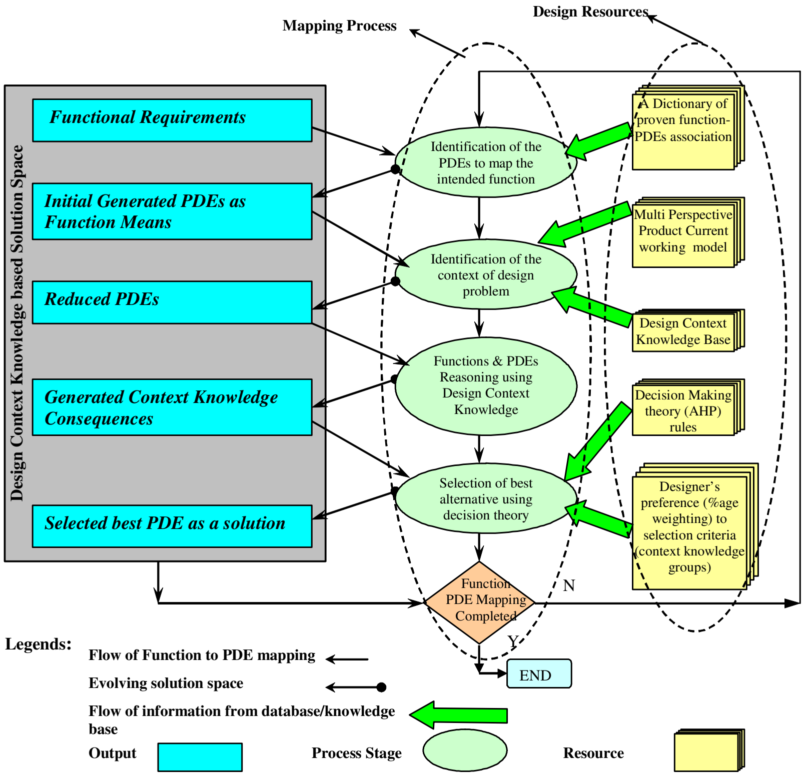


Figure 2. Function to PDE mapping model

The model consists of three groups of information or activities. The first group (i.e. the left hand column of the shaded rectangular box) is called the *Design Context Knowledge Based Solution Storage* and models a solution space in which the new decision made from an earlier design stage becomes the output to support the subsequent stage of the function to PDE mapping process. The second group (i.e. the right hand column of multiple square blocks) is called *Design Resources* and consists of resources to support the decision making. These include database, library of functions, function means association dictionary, design context knowledge base, Analytic Hierarchy Process (AHP) [23] rules and designer preferences through which knowledge/information is input to different stages of function to PDE mapping process. The third group (i.e. the central column of the oval shaped blocks) is called the *Design Context Knowledge Based Mapping Process* and describes the four stages of function to PDE mapping process, which is detailed below.

At every stage during the mapping process, the designer uses the inputs from the solution space and the design resources and generates new potential solution(s) thereby evolving the design solution. During the first stage, the designer takes the *Functional Requirements* and a *Dictionary of Proven Function-PDEs association* as inputs which result in *Initial Generated PDEs as output.* At the second stage, the designer takes these *Initial Generated PDEs* and searches for suitable models from the *Multi Perspective Product Current Working Model* library. This *Current Working Model* and the *Design Context Knowledge Base* are used to identify the exact context of the design problem i.e. functional requirements and solution information in different contexts. The design context knowledge base also facilitates the designer to reduce the initial set of PDEs into a reduced sub-set of PDEs, which don't comply with the desired physical properties as defined in the functional requirements.

During the third stage, the designer takes this reduced set of PDEs as inputs and performs function and PDEs reasoning simultaneously using the design context knowledge to generate *Context Knowledge Consequences* as the output of this stage as shown in figure 3.

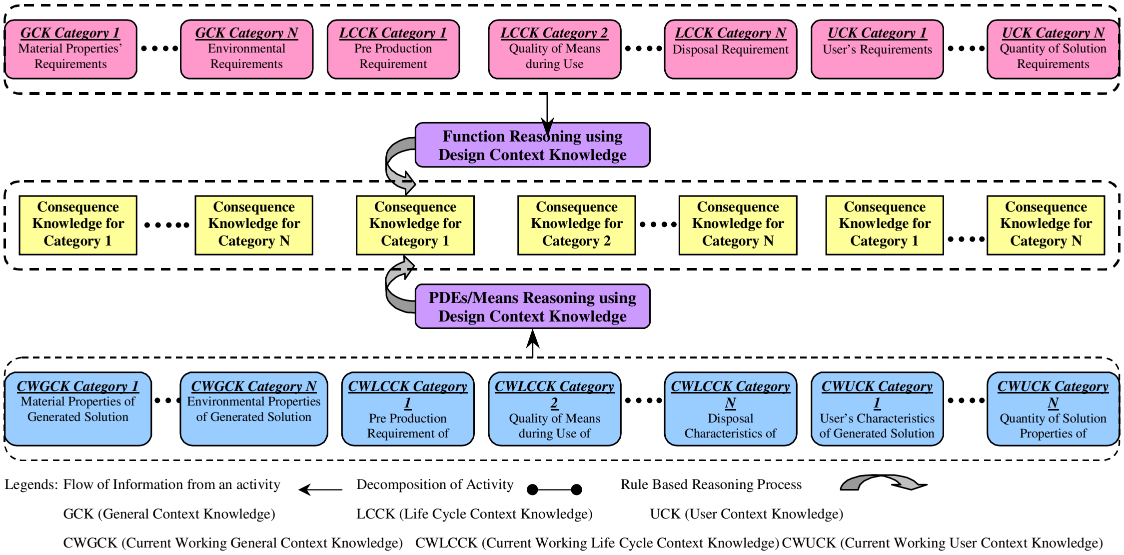


Figure 3. Consequences generation through reasoning process

At the final stage of the model, the designer uses the *Generated Context Knowledge Consequences, AHP rules* and the *Designer's Preference* as inputs and performs *decision making* by selecting the *best solution,* which not only fulfils the functional requirements, but also accounts for the whole context of the design problem under consideration. This life cycle awareness is performed, by timely prompting the designer about these consequences, thereby providing proactive decision making support to the designer.

This whole process of function to PDE mapping spanning these four stages, is iterated for all functions in a given design problem, until all functions are realized by selecting the best solutions as described above. At this stage, function to PDE mapping is completed for a design problem.

5 THE IMPLEMENTATION OF THE FRAMEWORK MODEL

It can be a demanding task if each of the PDEs generated is fully manually evaluated. In addition, the deadline for a design solution can be quite tight. To support effectively designers in these scenarios and too illustrate the effectiveness of the approach, function to PDE mapping model has been implemented into a *Knowledge-Intensive-CAD* prototype system known as PROCONDES acronyms of *Pro*-Active *Con*ceptual *Des*ign for the sheet metal component domain [24].

5.1 PROCONDES system architecture

PROCONDES system architecture as shown in figure 4 comprises a knowledge base, working memory, inference engine, tools and user interface.

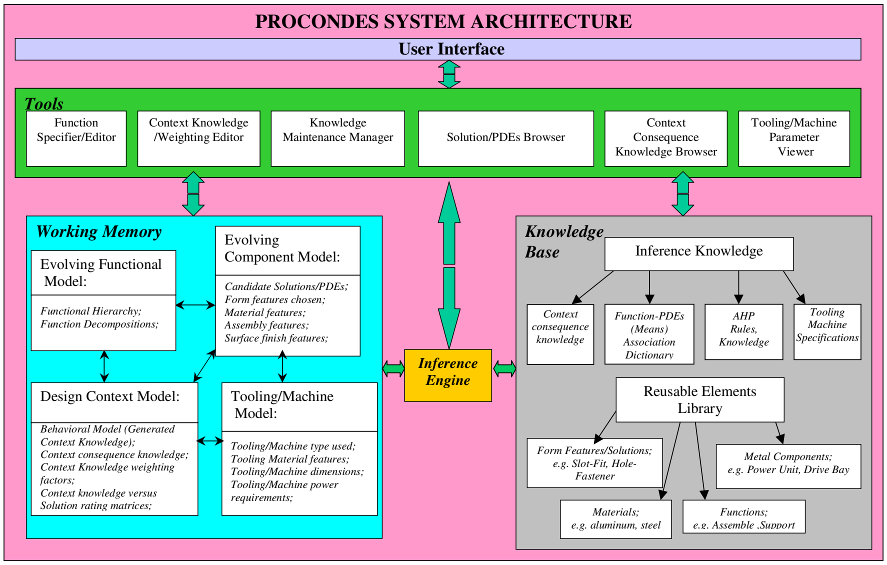


Figure 4. PROCONDES system architecture

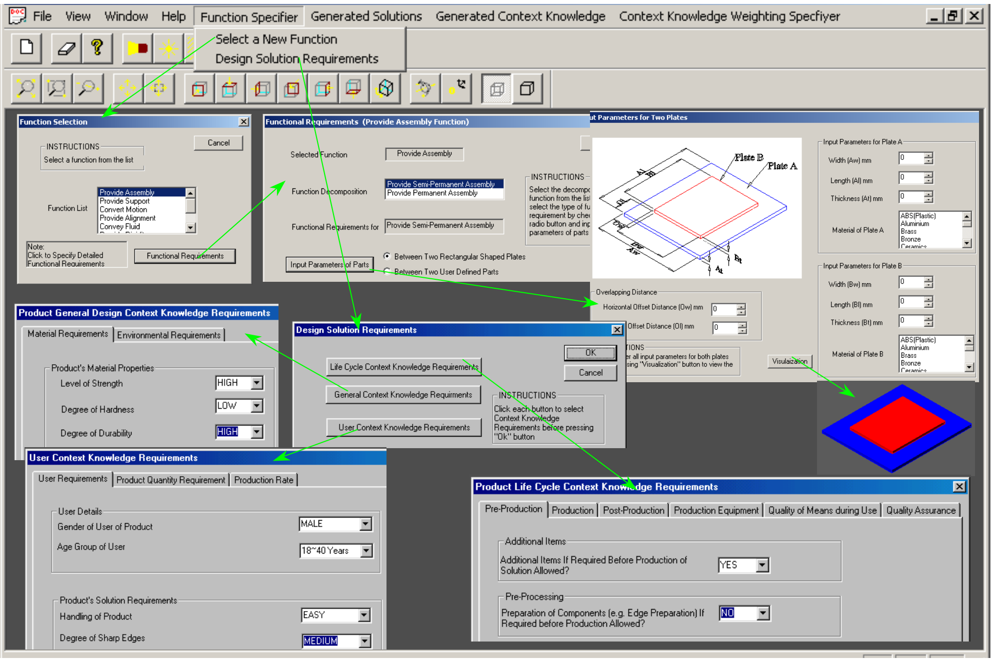
The *Knowledge Base* consists of Inference knowledge containing design consequence knowledge, function-PDEs association knowledge and Tooling/Machine specifications whereas Reusable Elements library consists of different types of features like form features, material features, functional features and standard components. *Working memory* stores the resultant information about the functional model, context knowledge model, evolving component model and its manufacturing life-phase model (Tooling/Machine model) derived from a concurrent synthesis. The *Inference engine* is the context knowledge based reasoning mechanism, containing rules based on DFX [25] methodologies to reason with the generated and required information. A set of tools has also been designed to facilitate the communication between a user and the Knowledge Base. These include: a *Function Specifier/Editor* to select or change a desired function, *Solution/PDEs Browser* to visualise the generated solutions, a *Context Consequence Knowledge Browser* to see the consequences that would occur during product development caused by design decisions, a *Context Knowledge Weighting Editor* in order to specify the designer's weighting to different criterion of decision making, a *Tooling/Machine Parameter Viewer* to see the design parameters required to manufacture a form feature.

5.2 System implementation

The architecture has been implemented using Microsoft Visual C++ version 6 on Windows 2000 and open GL libraries based system called Open CASCADE [26]. The prototype has been tested by demonstrating case studies to various researches of engineering design and in the process of further development and refinement. Development of a computational prototype incorporating this research approach provides real time support for designers during designing. Next section provides an illustration of the use of the system through captured screen images of a case study.

6 CASE STUDY

A case study of supporting conceptual design of a sheet metal component using design context knowledge background reasoning is presented in this section. The case study is about to identify suitable PDEs/solutions to a functional requirement and then evaluate and select the best solution using context knowledge reasoning using different functionalities of the system. Following paragraphs show the step-by-step procedure of performing this case study using the prototype system.
The main window of PROCONDES prototype system is shown as screen dump in figure 5. The first step is to select a new function from the *Function Selection* dialog box specified under the menu of *Function Specifier.* A *"Provide Assembly*" function is selected in this case study from the list of functions and functional requirements are specified in *Functional Requirements* dialog box. "*Provide Semi-Permanent Assembly Between Two Rectangular Plates"* has been selected as a decomposed function in this dialog box for further exploration. Detailed parameters of these plates are input by using 'Input Parameters of Parts' button, which displays a new dialog box. Different parameters of two plates like width, length, material etc. are selected and the two plates can be visualized using *Visualization* button option. Detailed functional requirements are input by using *Design Solution Requirements* Dialog Box through which *Life Cycle, General and User Context Knowledge Requirements* can be specified by selecting different parameters under different categories of knowledge in each one of the three groups as shown in figure 5.



INSTRUCTIONS
Select a function from the list

Function List: Provide Assembly, Provide Support, Convert Motion, Provide Alignment, Convey Fluid

Note:
Click to Specify Detailed Functional Requirements

Selected Function: Provide Assembly

Function Decomposition: Provide Semi-Permanent Assembly, Provide Permanent Assembly

Functional Requirements for: Provide Semi-Permanent Assembly

● Between Two Rectangular Shaped Plates
○ Between Two User Defined Parts

Input Parameters for Plate A
Width (Aw) mm: 0
Length (Al) mm: 0
Thickness (At) mm: 0
Material of Plate A: ABS(Plastic), Aluminium, Brass, Bronze, Ceramics

Input Parameters for Plate B
Width (Bw) mm: 0
Length (Bl) mm: 0
Thickness (Bt) mm: 0
Material of Plate B: ABS(Plastic), Aluminium, Brass, Bronze, Ceramics

Overlapping Distance
Horizontal Offset Distance (Ow) mm: 0
Offset Distance (Ol) mm: 0

INSTRUCTIONS
Click each button to select Context Knowledge Requirements before pressing "Ok" button

Product's Material Properties
Level of Strength: HIGH
Degree of Hardness: LOW
Degree of Durability: HIGH

User Details
Gender of User of Product: MALE
Age Group of User: 18~40 Years

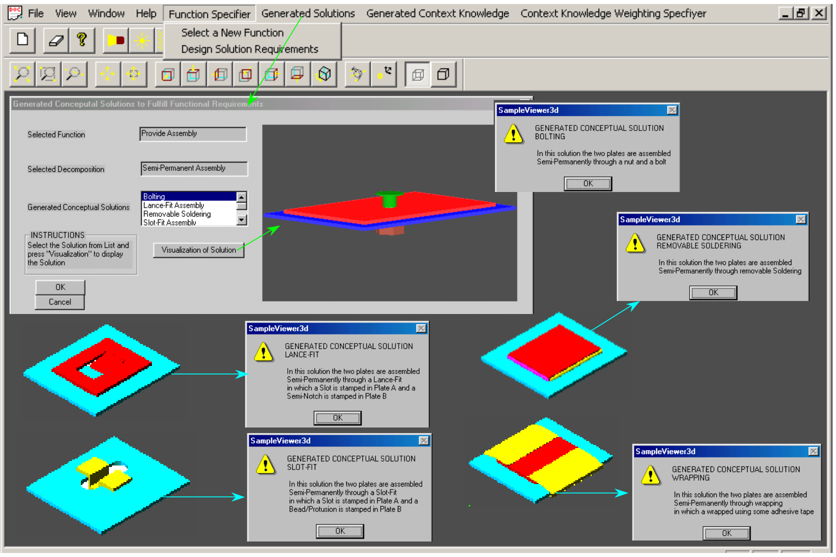
Product's Solution Requirements
Handling of Product: EASY
Degree of Sharp Edges: MEDIUM

Additional Items
Additional Items If Required Before Production of Solution Allowed?: YES

Pre-Processing
Preparation of Components (e.g. Edge Preparation) If Required before Production Allowed?: NO

Figure 5. Screen dump of PROCONDES showing input of functional requirements

Once the functional requirements are specified, the next step is to find the initial generated solutions in terms of PDEs. Generated solutions can be viewed through *Generated Conceptual Solutions to Fulfil Functional Requirements* dialog box. Five initial PDEs namely *Bolting, Lance-Fit Assembly, Slot-Fit Assembly, Removable Soldering and Tape Wrapping* are identified from dictionary of Function-PDEs association. Detail of each one of these solution PDEs can be illustrated graphically & textually by pressing *'Visualization of Solution'* button option as shown as a screen dump in figure 6. Once a list of suitable PDEs is generated, then context of design problem using design context knowledgebase and multi-perspective product current working model is identified. Thus generated context knowledge for different solution PDEs can be viewed in different categories of context knowledge through three groups of dialog boxes *Generated Life Cycle Context Knowledge, Generated User Context Knowledge and Generated General Context Knowledge* as shown in figure 7. Context consequence knowledge/information is generated regarding each one of these means/solutions in each one of the categories of context knowledge. This information is generated by simultaneously reasoning the design solution requirements as well as generated context knowledge for the design solution under consideration. This type of early awareness knowledge pertaining to later life cycle phases about a design solution provides proactive support to the designer in selecting a solution, which will cause fewer problems in later life cycle phases.



Generated Conceptual Solutions to Fulfill Functional Requirements

Selected Function: Provide Assembly

Selected Decomposition: Semi-Permanent Assembly

Generated Conceptual Solutions: Bolting
Lance-Fit Assembly
Removable Soldering
Slot-Fit Assembly

INSTRUCTIONS
Select the Solution from List and press "Visualization" to display the Solution

GENERATED CONCEPTUAL SOLUTION
BOLTING
In this solution the two plates are assembled Semi-Permanently through a nut and a bolt

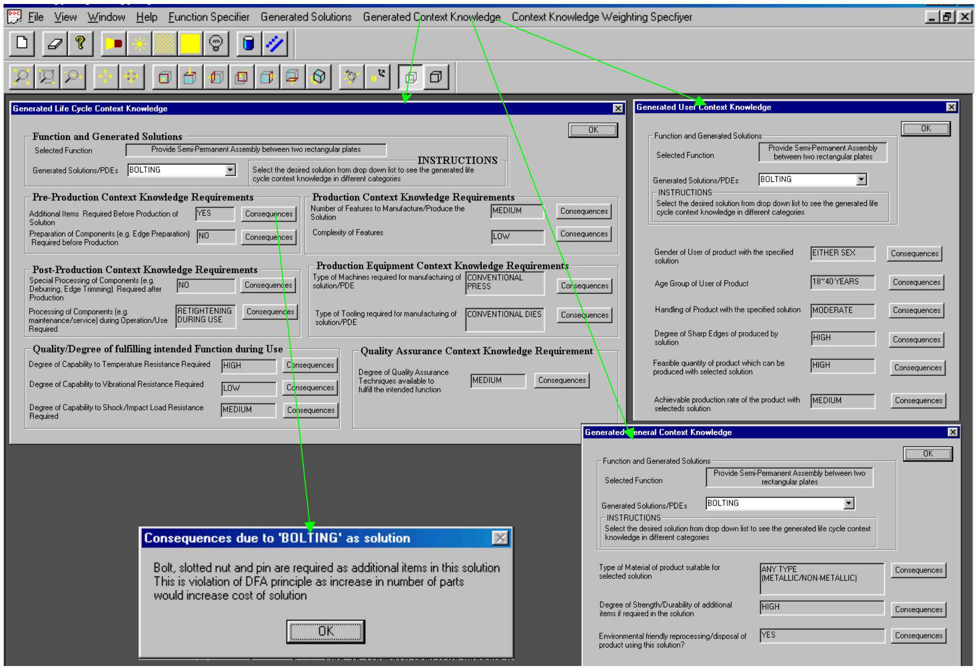
GENERATED CONCEPTUAL SOLUTION
REMOVABLE SOLDERING
In this solution the two plates are assembled Semi-Permanently through removable Soldering

GENERATED CONCEPTUAL SOLUTION
LANCE-FIT
In this solution the two plates are assembled Semi-Permanently through a Lance-Fit in which a Slot is stamped in Plate A and a Semi-Notch is stamped in Plate B

GENERATED CONCEPTUAL SOLUTION
SLOT-FIT
In this solution the two plates are assembled Semi-Permanently through a Slot-Fit in which a Slot is stamped in Plate A and a Bead/Protusion is stamped in Plate B

GENERATED CONCEPTUAL SOLUTION
WRAPPING
In this solution the two plates are assembled Semi-Permanently through wrapping in which a wrapped using some adhesive tape

Figure 6. Screen dump of PROCONDES showing initial generated PDEs



Generated Life Cycle Context Knowledge

Function and Generated Solutions
Selected Function: Provide Semi-Permanent Assembly between two rectangular plates
Generated Solutions/PDEs: BOLTING

INSTRUCTIONS
Select the desired solution from drop down list to see the generated life cycle context knowledge in different categories

Pre-Production Context Knowledge Requirements
Additional Items Required Before Production of Solution: YES
Preparation of Components (e.g. Edge Preparation) Required before Production: NO

Production Context Knowledge Requirements
Number of Features to Manufacture/Produce the Solution: MEDIUM
Complexity of Features: LOW

Post-Production Context Knowledge Requirements
Special Processing of Components (e.g. Deburring, Edge Trimming) Required after Production: NO
Processing of Components (e.g. maintenance/service) during Operation/Use Required: RETIGHTENING DURING USE

Production Equipment Context Knowledge Requirements
Type of Machines required for manufacturing of solution/PDE: CONVENTIONAL PRESS
Type of Tooling required for manufacturing of solution/PDE: CONVENTIONAL DIES

Quality/Degree of fulfilling intended Function during Use
Degree of Capability to Temperature Resistance Required: HIGH
Degree of Capability to Vibrational Resistance Required: LOW
Degree of Capability to Shock/Impact Load Resistance Required: MEDIUM

Quality Assurance Context Knowledge Requirement
Degree of Quality Assurance Techniques available to fulfill the intended function: MEDIUM

Generated User Context Knowledge

Function and Generated Solutions
Selected Function: Provide Semi-Permanent Assembly between two rectangular plates
Generated Solutions/PDEs: BOLTING

INSTRUCTIONS
Select the desired solution from drop down list to see the generated life cycle context knowledge in different categories

Gender of User of product with the specified solution: EITHER SEX
Age Group of User of Product: 18~40 YEARS
Handling of Product with the specified solution: MODERATE
Degree of Sharp Edges of produced by solution: HIGH
Feasible quantity of product which can be produced with selected solution: HIGH
Achievable production rate of the product with selecteds solution: MEDIUM

Generated General Context Knowledge

Function and Generated Solutions
Selected Function: Provide Semi-Permanent Assembly between two rectangular plates
Generated Solutions/PDEs: BOLTING

INSTRUCTIONS
Select the desired solution from drop down list to see the generated life cycle context knowledge in different categories

Type of Material of product suitable for selected solution: ANY TYPE (METALLIC/NON-METALLIC)
Degree of Strength/Durability of additional items if required in the solution: HIGH
Environmental friendly reprocessing/disposal of product using this solution?: YES

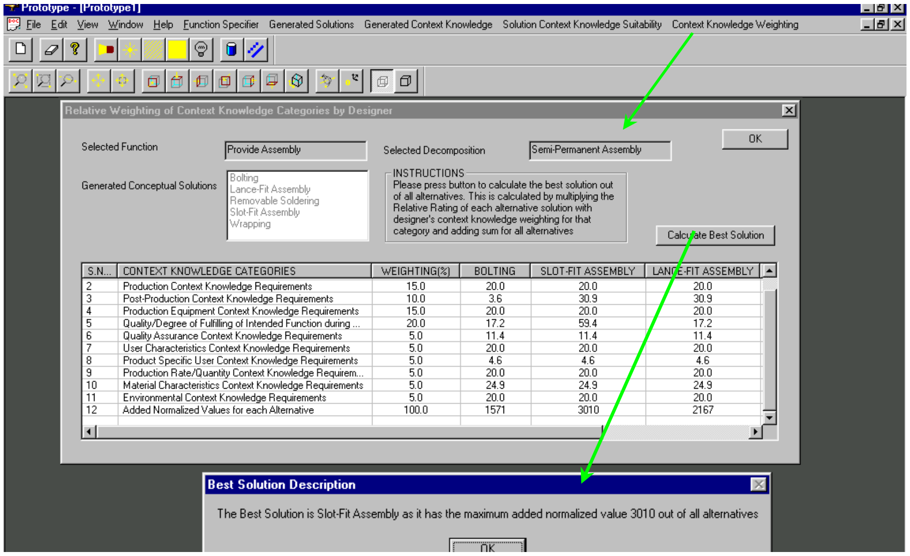
Consequences due to 'BOLTING' as solution

Bolt, slotted nut and pin are required as additional items in this solution
This is violation of DFA principle as increase in number of parts
would increase cost of solution

Figure 7. Screen dump of PROCONDES showing generated context knowledge of PDEs

For example a *"Bolting"* solution requires "YES" against the slot of *'Additional Items Required before Production of Solution'* under Life Cycle Context Knowledge Group. Reasoning process illustrates consequences due to 'Bolting' as solution, which are *Bolt, Slotted Nut and Pin as additional items in this solution*. This is violation of DFA principle, as it would increase the cost and time of solution to manufacture. Timely prompting designer about this manufacturing phase consequence forces designer to think about other possible solutions as well before making a final decision.

Once the design solution/life cycle consequences are illustrated for different scenarios for each of the PDE, it is possible to rate each design solution/means in terms of degree of suitability for that particular context knowledge category. The higher the degree the more suitable is solution regarding the category under consideration. The fewer the problematic consequences, the higher the degree of suitability. The assignment of numerical ratings to each of design alternatives under each context knowledge criterion category is done by converting degree of suitabilities of each alternative described in previous section into weighting factor. This is done by using the comparison scales defined in Analytic Hierarchy Process (AHP) [23] a decision making theory for decision-making and selection of optimal PDE alternative at conceptual design stage for mechanical artefact design. These numerical ratings against each criterion in terms of percentage weightings are shown as a screen dump in figure 8 under different columns of PDEs such as BOLTING, SLOT-FIT ASSEMBLY etc. The relative weighting among different knowledge criteria (preference of one criterion over other) can be done by giving percentage weighting out of 100 for each context knowledge categories. Assignment of relative weighting is controlled by the designer and depends upon lots of factors like consideration of cost, designer's preference, and company policy. For example some companies prefer low cost of products, compromising the quality of products. In this case study the relative weightings taken as designer's preference are shown in figure 8 under WEIGHTING (%) column. After determining relative weighting of each criterion and the numerical rating of alternatives, the final task in this case study is to find the best design solution/alternative against the predefined weightings out of these five alternatives *(Lance-Fit Assembly, Slot-Fit Assembly, Bolting, Removable Soldering, Tape Wrapping).* This is done by calculating the highest added normalized value for each design alternative PDE. Figure 8 shows that that the highest added normalized value is *3010* for ***Slot-Fit Assembly***; therefore ***Slot-Fit*** is the best alternative for the given weighting out of five alternatives in order to provide *Semi-Permanent Assembly* between *two rectangular plates.*



Selected Function: Provide Assembly

Selected Decomposition: Semi-Permanent Assembly

Generated Conceptual Solutions:
Bolting
Lance-Fit Assembly
Removable Soldering
Slot-Fit Assembly
Wrapping

INSTRUCTIONS
Please press button to calculate the best solution out of all alternatives. This is calculated by multiplying the Relative Rating of each alternative solution with designer's context knowledge weighting for that category and adding sum for all alternatives

S.N...	CONTEXT KNOWLEDGE CATEGORIES	WEIGHTING(%)	BOLTING	SLOT-FIT ASSEMBLY	LANCE-FIT ASSEMBLY
2	Production Context Knowledge Requirements	15.0	20.0	20.0	20.0
3	Post-Production Context Knowledge Requirements	10.0	3.6	30.9	30.9
4	Production Equipment Context Knowledge Requirements	15.0	20.0	20.0	20.0
5	Quality/Degree of Fulfilling of Intended Function during ...	20.0	17.2	59.4	17.2
6	Quality Assurance Context Knowledge Requirements	5.0	11.4	11.4	11.4
7	User Characteristics Context Knowledge Requirements	5.0	20.0	20.0	20.0
8	Product Specific User Context Knowledge Requirements	5.0	4.6	4.6	4.6
9	Production Rate/Quantity Context Knowledge Requirem...	5.0	20.0	20.0	20.0
10	Material Characteristics Context Knowledge Requirements	5.0	24.9	24.9	24.9
11	Environmental Context Knowledge Requirements	5.0	20.0	20.0	20.0
12	Added Normalized Values for each Alternative	100.0	1571	3010	2167

The Best Solution is Slot-Fit Assembly as it has the maximum added normalized value 3010 out of all alternatives

Figure 8. Screen dump of PROCONDES showing context knowledge weighting and best-selected solution PDE

7 PROCONDES EVALUATION

The above case study of sheet metal component design problem was performed on PROCONDES system with a sample size of nineteen different people who were researchers, designers and engineering design students. A detailed comprehensive questionnaire which contains questions related to different functionalities of PROCONDES system as well as the overall function to PDE mapping model were presented to them after performing the case study in order to evaluate both the model and the system in detail. Some of the critical evaluation results are presented here regarding performance/output of system in different areas.

7.1 Context knowledge and consequences' awareness

67% of the evaluators agreed that the context knowledge generated under three different groups in different categories is detailed enough to foresee the impact of selecting a particular solution on different life cycle phases, user of product and environment of product. Some evaluators suggested that there could be more context knowledge categories that should be considered in the case study performed as well as in each category there could be more knowledge that should be considered in addition to what presented in the case study. 59% of the evaluators confirmed that they were made aware of all the consequences related to a chosen context knowledge category early at design stage of selecting a particular conceptual design solution in detail. However most of the evaluators suggested in explaining a consequence in detail as well as more consequences should be generated related to each context knowledge category under three different groups while selecting a particular conceptual design solution.

Please tick where appropriate and feel free to add your reasons while answering any question.

1. Do you think that PROCONDES decomposed the functional requirements and explained them in an appropriate manner to you of the case study run for this demonstration?

[✓ YES] NO OTHER

I think it can explain them clearly.

2. Did PROCONDES elaborate the design solution requirements in detail by splitting them into three groups?

[✓ YES] NO OTHER

Grouping is a good way. Maybe it should be extended.

3. Was the method of selecting/input of functional requirements under different categories against each group right?

[✓ YES] NO OTHER

4. Did the explanation of generated conceptual solutions to realize a particular functional requirement was enough in

Graphical Form? [✓ YES] NO OTHER

Very clearly. it can be viewed in diffrent way.

Textual Form? YES NO [✓ OTHER]

I mean it is good. but it can be improved more.

5. Do you think that PROCONDES has enough functionalities (zoom, pan, dynamic rotate, view) in displaying the generated conceptual solution in graphical form?

[✓ YES] NO OTHER

6. Do you think the context knowledge generated under three groups in different categories is detailed enough to foresee the impact of selecting a particular solution on different life cycle phases, user of product and environment of product?

[✓ YES] NO OTHER

7. Were you made aware of consequences of selecting a particular solution in detail on later life cycle stages?

[✓ YES] NO OTHER

I can have the idea that I can know the consequences from the conceptual design in detail.

Evaluation Questionnaire of PROCONDES system

8. Do you think that the concept of assigning degrees of suitability to a particular solution based on context knowledge reasoning is a just indication of appropriateness of a solution against a criterion?

[✓ YES] NO OTHER

9. Do you think the scale of suitability (5~0) is a fair indication of appropriateness of a solution against a criterion?

[✓ YES] NO OTHER

I think it is enough to indicate the suitability in conceptual desig

10. Did PROCONDES show you the suitability of a particular solution to a context knowledge category in terms of percentage weighting out of rest of the design alternatives?

[✓ YES] NO OTHER

11. Do you think that designer should be allowed to indicate his/her preference in terms of percentage weighting (as shown in PROCONDES) or in linguistic rating scales (Absolutely necessary, Very Important, Important etc.)?

[✓ YES] NO OTHER

I think both of them are preferable.

12. Did PROCONDES show you the best solution out of all design alternatives after calculating the highest aggregated normalized value?

[✓ YES] NO OTHER

I think after the calculation, the software should give the conclusion.

13. Do you think that PROCONDES demonstrated its abilities in providing a proactive support to a designer during case study by: -

- Highlighting the potential consequences of selecting a particular solution?

  [✓ YES] NO OTHER

- Providing a decision support through evaluating all candidate design solutions against different context knowledge criteria?

  [✓ YES] NO OTHER

Evaluation Questionnaire of PROCONDES system

- Selecting a best solution which not only fulfills functional requirements, designer's preference but also suitable for later life cycle stages thereby reducing the cost and time which would be incurred of selecting a particular solution without knowing its suitability for later life cycle stages?

  [✓ YES] NO OTHER

It can support the decision-making of the designer.

14. Do you any other recommendations/suggestions to

- This approach of proactively supporting decision making at conceptual design stage?

  Because creation is the core of conceptual design, if the software can support the creative design, it must be very excellent.

  PROCONDES prototype system?

  I thin the prototype system is a very good one, and maybe it can plus a wizard manner to use it.

  The example/case study performed during this demonstration?

  I think the example is clear enough.

15. Do you think some other important questions/issues, which are not given in this questionnaire or not highlighted during this demonstration?

the function of collaborative design.

16. Your current role (Researcher, Academics, Designer, Student)?

Student

17. Type of institution/company (Industry, Academics)?

Academics

Figure 10. A Sample of filled Questionnaire

7.2 Context knowledge suitability

All evaluators (100%) agreed with the concept of assigning degrees of suitability to a particular solution based on context knowledge reasoning as a just indication of appropriateness of a conceptual design solution against a criterion. 67% of evaluators agreed that the scale of suitability from 0 to 5 set in PROCONDES is a fair indication of appropriateness of a solution against a criterion. Moreover 92% of evaluators agreed with the idea of allowing designer's preference in percentage weighting instead of linguistic rating scales.

7.3 Decision support

Responses to the question about decision support capabilities indicated that PROCONDES demonstrated its abilities in providing a proactive decision support to a designer during case study by a) generating and highlighting the potential consequences of selecting a particular solution (92% of evaluators); b) evaluating all candidate design solutions against different context knowledge criteria (75% of evaluators); c) selecting a best solution for the case study which not only fulfils functional requirements, designer's preference but also suitable for later life cycle stages thereby reducing the cost and time which would be incurred of selecting a particular solution without knowing its suitability for later life cycle stages (67% of evaluators).

7.4 PROCONDES system and overall approach

Upon asking about recommendations/suggestions to overall approach and PROCONDES system, most of the researchers appreciated the approach of proactively supporting decision making at conceptual design stage using context knowledge reasoning as one of the evaluators said: -

> *"It is good for designers and helps in the course of designing"*

Some researchers expressed their opinion to add more context knowledge and consequences in each context knowledge category. Regarding PROCONDES system functionalities, most of the evaluators appreciated the graphical user interface of the system and corresponding functionalities to view and display conceptual solutions. However as far as textual interface and explanation of solutions is concerned, majority of them stressed to make it more presentable in clear textual form in detail. Some evaluators suggested adding concurrent design process of component (i.e. generation of basic tooling and machine parameters) along with conceptual design solutions as originally proposed in the architecture of the system, which could not be accomplished in this version. Some researchers also suggested codifying some more complex case studies in the PROCONDES system.

8 CONCLUSIONS

From this paper, it can be concluded that:

- By formalizing and fully representing design context knowledge, a designer, with the help of a computer based system such as PROCONDES, can be empowered to foresee potential life cycle and other design decision consequences. This capability can change the way designing is carried out and enhance the existing design process considerably. Design context knowledge in the background of design process helps designers to process vast amounts of potentially related design information and prompts useful insights when they are available through reasoning. Reasoning using context knowledge can further assist designers to concentrate on exploring design alternatives and generate more innovative design solutions. All these help to reduce and eliminate the chances of redesign as life cycle implications have been considered earlier at the conceptual design synthesis stage due to the selection of a particular solution.
- The developed PROCONDES system successfully highlights the potential good and bad/problematic consequences to the designer earlier at the conceptual design stage. This provides proactive decision support as well as establishes a mechanism to select best solution against functional requirements and different life cycle implications thus supporting conceptual design synthesis for Multi-X.

REFERENCES

[1] Pugh S. *Total Design: Integrated Methods for Successful Product Engineering*, 1990, Publishers Addison-Wesley Ltd.

[2] Lotter B. *Manufacturing assembly handbook*, 1986, Boston: Butterworths.

[3] Rehman F. Yan X.T. and Borg, J. C. Conceptual design decision making using design context knowledge, In *5th International Conference on Integrated Design and Manufacturing in Mechanical Engineering (IDMME 2004),* Bath, UK, April 5-7, 2004, pp 107.

[4] Rehman F. *A Framework for Conceptual Design Decision Support*, 2006, CAD centre, Dept. of DMEM, University of Strathclyde, Glasgow, UK.

[5] Mistree F. and Smith W. A decision-based approach to concurrent design, *Concurrent Engineering-Contemporary Issues and Modern Design Tools*, 1993, H.R. Parsaei and W.G.

Sullivan, London, Chapman & Hall, pp. 127-158.
[6] Starvey C.V. *Engineering Design Decisions*, 1992, Edward Arnold, London.
[7] Joshi, S.P. Decision making in Preliminary Engineering Design, *Artificial Intelligence in Engineering Design and Manufacture*, 1991, 5(1), 21-30.
[8] Duckworth A.P. and Baines R.W. An Eco-Design Framework for Small and Medium Sized Manufacturing Enterprises, *2nd International Symposium 'Tools and Methods For Concurrent Engineering'*, 1998, Manchester, UK, pp. 132-141.
[9] Hubka V. and Eder W.E. *Theory of Technical Systems: a Total Concept Theory of for Engineering Design*, 1988, Berlin: Springer Verlag.
[10] Andreasen M. M. and Olesen J. The Concept of Dispositions*, Journal of Engineering Design*, 1990, 1(1), 17-36.
[11] Duffy A. H. B. and Andreasen M.M. Design Co-ordination for Concurrent Engineering, *Journal of Engineering Design*, 1993, 4(4), 251-265.
[12] Borg, J. C. and Yan, X.T. Design Decision Consequences: Key to 'Design For Multi-X' Support', *In 2nd International Symposium 'Tools and Methods for Concurrent Engineering*, 1998, Manchester, UK, pp. 169-184.
[13] Gero J. S. Conceptual designing as a sequence of situated acts, *Artificial Intelligence in Structural Engineering*, 1998, eds I. Smith, Springer, Berlin, pp. 165-177.
[14] Oxford *The New Oxford Dictionary of English,* 1998*,* Oxford University Press, UK.
[15] Charlton, C. and Wallace, K. Reminding and context in design, *In Artificial Intelligence in Design 2000,* 2000, Massachusetts, USA, pp. 596-588.
[16] Zhang Y. *Computer-based modelling and management for current working knowledge evolution*, 1998, PhD Thesis, Strathclyde University, UK.
[17] Yan, X.T. Rehman, F. Borg, J.C. FORESEEing design solution consequences using design context information, *In 5th IFP Workshop in Knowledge-Intensive Computer–Aided Design,*2002, Malta, pp.18-33.
[18] Borg, C. J. and MacCallum K.J. A Life-Cycle Consequences Model Approach To The Design For Multi-X of Components, In *11th International Conference on Engineering Design (ICED97)*, 1997, Tampere, Finland, pp. 647-652.
[19] Borg, C. J. Yan, X. T. Juster, N. P. Guiding component form design using decision consequence knowledge support, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 1999, 13, 387-403.
[20] Welch R. V. and Dixon J. R. Representing function, behaviour and structure during conceptual design, *In ASME Design Theory and Methodology Conference,* 1992,Scottsdale, USA, pp.11-18.
[21] Andreasen, M.M. and Hansen, C.T. The Structuring of Products and Product Programmes, *In 2nd WDK Workshop on Product Structuring*, 1996, Delft University, The Netherlands, pp. 14-53.
[22] Rehman, F. and Yan, X.T. Product design elements as means to realize functions in mechanical conceptual design, *In 14th International Conference on Engineering Design ICED 03*, 2003, Stockholm, Sweden, pp. 213.
[23] Saaty, T.L. How to Make a Decision: The Analytic Hierarchy Process, *European Journal of Operational Research,* 1990, 48, 9-26.
[24] Rehman, F. and Yan, X.T. A prototype system to support conceptual design synthesis for Multi-X, *In 15th International Conference on Engineering Design ICED 05*, 200, Melbourne, Australia, pp. 479.
[25] Huang, G.Q. *Design for X: concurrent engineering imperatives*, 1996, London, Chapman & Hall.
[26] Open CASCADE 5.0 Documentation by Open CASCADE, *Headquarters Immeuble Ariane Domaine Technologique de Saclay 4, rue René Razel*, 2003, 91400 SACLAY, France.

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