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Invited Paper

Creative Approaches in Product Design

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Abstract

This research paper presents a knowledge-based system for creative design tools (CDT). The main aim of the developed CDT system is to provide designers with a flexible creative design environment to enhance their creative design thinking. Several creative thinking tools are developed and integrated with constructive knowledge databases to widen the search space and expand the design domain. CDT incorporates: a user interface, creativity tools, knowledge databases and five design modules namely: preparation, concept generation, design development, evaluation, and detailed design. A case study is discussed and demonstrated to validate the developed system.

Keywords:

Creative design, Design computation, Creative design tools, Product design, Knowledge-based systems

1 INTRODUCTION

Design is considered a goal-oriented, problem-solving activity that relies on many several factors, namely human experience, creative thinking and related knowledge. Creative design thinking can be supported by providing the suitable means through developing creative design environments which incorporate the necessary elements for creative thinking using design computation. Such creative design environments require the investigation of various domains such as design, creativity, design computation, and collaboration in design. This research paper presents a holistic approach in developing such computational design environments using advanced computer technologies to support creative design thinking.

The main aim is to provide design groups with flexible design environments to escape the routine design space to a more non-routine design solution space [1]. The identification of new design knowledge by fluent interaction between designers and knowledge [2], flexibility in defining requirements and constraints, integrity of the whole design process with creative methods and tools that can assist the creation of new design solution spaces with several channels of exploration open in parallel [3] [4], are considered essential solutions to achieve that main aim.

Creativity involves four components: the creative process, creative product, creative person, and creative situation [5]. Abstraction is vital to the creative process through using old information and expressing it in an abstract form [6]. This helps the identification of goals and the development of new creative ideas. To meet these goals other means such as processes and methods are essential. Three types of creativity are distinguished according to the process used in generating creative ideas: combinational, exploratory, and transformational [7]. Various ways are relevant to encourage creativity depending on its type. For combinational type as an example; widening the general design knowledge, experimenting unfamiliar combinations, and an evaluating criteria to pick the proper solutions are proposed.

Creative methods usually work by increasing the flow of ideas, removing mental blocks, and widening the search area for solutions [8]. These creative methods can be achieved by using special type of tools. For example to increase the flow of ideas brainstorming can be used to produce a large number of alternatives. Furthermore, the use of analogical thinking can eliminate mental blocks. On the other hand widening the search space can be achieved through evolutionary and combinational tools [9] [10] [11].

Various creative design models were proposed in the literature. Simon model [12] was based on the personal view of creativity by hypothesizing that creativity is a special kind of problem solving behavior which satisfies novelty and value of the resulted product for the designer and his/her culture, unconventional thinking, high motivation, and ill defined problems to be formulated through the design process. On the other hand, Csikszentmihalyi developed the social-cultural creativity model on where is creativity not on what is creativity [13] . His framework composed of three major elements: the person, the field, and the domain. The occurrence of a creative idea, object, or action is determined by the jointly relation between those three elements. An idea is realized as creative if the person recognizes it and the society additionally. Based on those two models Liu proposed the dual generate-and-test model [14]. This dual model encapsulates two generate-and-test loops; one at the level of the individual, and the other at the level of society.

Creative design is not fixing the problem and searching for solution, it is more into developing and refining both the problem formulation and the solution [15]. This can be achieved by repetition of analysis, synthesis, and evaluation processes between the problem space and the solution space. The essential stages of divergence, transformation, and convergence were proposed in Hsiao and Chou model of creativity-based design process [16]. Their method contained personal behaviors of human sensuousness such as looking, thinking, comparing, and describing accompanied by stimulation which is an extrinsic influence of the environment.

Requirements capture (RC) is usually at the front end of the design process in any new product development. It is the process of research and identification of the customer, user, market, design, and technical requirements. It is essential to conduct a thorough (RC) through information gathering, information transformation, and requirements generation to provide a basis to build design solutions and synthesis [17] [18].

Conceptual design is one of the early stages of design that demands the greatest creativity. Its main aim is to produce design principles concerning the product form and function to satisfy requirements and be competent [19]. Large numbers of concepts are usually generated at this stage. Two main steps of divergence and convergence are identified in conceptual design and were discussed by various researchers [20] [21]. A multiple divergence convergence approach was proposed to increase the number of the generated concepts to reach a level beyond abstraction to be understood by designers and reduce the solution space [22]. It was recognized that visualization facilitates the concept generation in any design process [23] [24]. The designers externalize their ideas using sketching or other ways of representations such as diagrams, concept maps, or documents using computers. The represented results inspire designers to generate new ideas or concepts [25] [26].

Creative problem solving in design using visual creative tools were discussed in the literature. Visual and classical brainstorming proved to assist design groups in their concept generation process [27]. Concept mapping proved to support creative thinking in general [28] and creative design thinking in specific [29] [30] [31]. It presents a holistic approach by making the structure of the problem more readable and act as memory aids to review the design problem at any stage of the design process [32].

Analogical reasoning is another technique to widen the design solution space. It is the transfer of knowledge between various domains based on similarities between the target and the source space. It involves three major phases: (1) identifying the source candidates for analogy matching and retrieval (2) mapping the source candidate with the target (3) transferring knowledge between the source and the target [33] [34].

It was recognized that combination and evolution play an important role in production of creative work in various disciplines and design is one of them. Combination involves the combining of two design concepts or subsets of them from similar or dissimilar unrelated ideas [35]. The combination can occur at various levels. Furthermore, evolutionary search algorithms look at a population of slightly different solutions at once, and then through cross over and mutation new generations are created. This tool proved to produce creative design solutions [33] [36].

Collaboration was recognized to support the design process by minimizing the lead time of the product development through sharing of information and resources between individuals and organisations. Several researchers indicated the benefits of collaboration through the different design processes [37] [38] [39]. Two collaboration modes were addressed: a horizontal and a hierarchical mode. These collaboration modes are complementary in functions. They established a vertical linkage between the design and the manufacturing processes, and a horizontal linkage of team work in the design phases [40].

The literature review indicated that a holistic approach is needed to enhance creative design thinking among design teams by providing an integrated flexible design environment with the proper knowledge, processes, and creative tools. Several limitations were addressed in the existing creative design models. They lacked the integration of various creative tools and processes with the proper constructive design knowledge, the use of flexible design representation which can be adjusted by designers and reflected to all users immediately, and the distance collaboration among design teams in the early stages of design at various locations.

To overcome those limitations, the CDT system has been developed taking into consideration all the aspects of creative design approaches the creative process, creative product, creative person, and creative situation.

2 CREATIVE DESIGN TOOLS MODEL

An integrated design framework is required to achieve efficiency among design groups, creativity and synchronization. Such a framework needs to be flexible to comply with the dynamic nature of the design process, provide a complementary support for designers' thinking activities, support smooth interface between designers and knowledge, and achieve interdisciplinary interaction between various processes of design. The proposed system framework encompasses constructive knowledge databases, creative tools, five design modules, and a user friendly interface. The overall structure of the CDT system is shown in Figure 1.

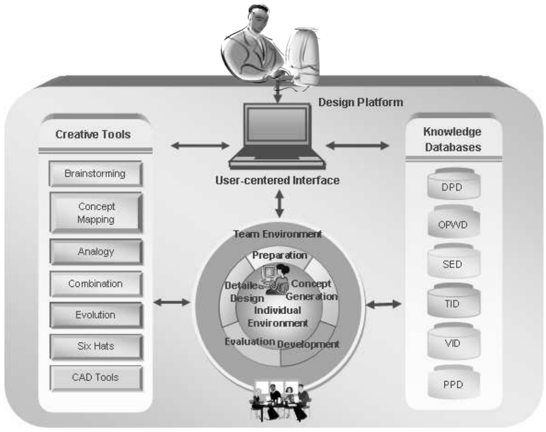

Figure 1: CDT Framework.

2.1 Constructive knowledge databases

It is essential that the designers are provided with suitable knowledge for each design task before starting the design process. The system encompasses several constructive databases which can provide various data required for the design task. The more the design teams become experienced the more expert their databases will become. The provided databases are dependent on the type and domain of the design problem. Six knowledge databases are incorporated which include: general project information (GPI), active projects information (API), general design knowledge (GDK), specific design knowledge (SDK), others sample designs (OSD), and previous project sample designs (PPSD).

Design knowledge representation

In the developed CDT system each design alternative is divided into major components, each major component is divided into items with different identified features which distinguish it and specify its characteristics. For each component and item in the design alternative detailed functions, behaviours, and structures are identified in addition to the general ones of the alternative in this hierarchical structure. The incorporated creative tools are structured and implemented based on this hierarchical design representation. Features are structured to include structural, behavioural, and functional data. Relationships between different parts of the designed sample are identified using objects tree hierarchical structure and methods embedded within each object. The data identified in those representations are stored in the databases and can be retrieved and used by all the incorporated creative tools.

Design knowledge has been represented in the proposed CDT system using structured hierarchical tree. This hierarchical tree has been selected because it has many advantages over other knowledge representational schemes. These advantages are reflected in their easy connectivity to the databases to store and retrieve data, the flexibility and expandability of its structure where designers can add, hide, or show more detailing as required, and its adaptability to represent any hierarchical design knowledge for any product. An illustration of the concept alternative representation is shown in Figure 2.

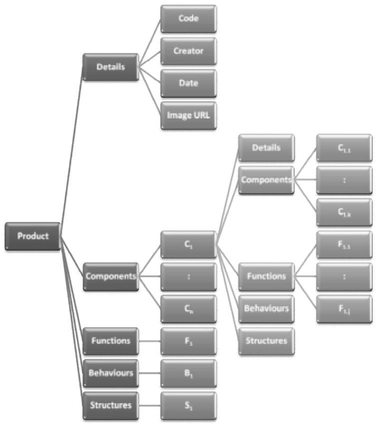

Figure 2: Concept alternative representation.

Design knowledge management

Microsoft Structured Query Language (SQL) server 2005 was used to create the databases of the CDT system. The data related to products, major components, items, behaviors, functions, and structures are stored in relational tables. The developed CDT system contains structured design knowledge in its databases and allows performing of certain operations on that data such as retrieval, modification, insertion, and deletion.

Data management in the developed CDT system has been divided into two major classes: general data management, and specific data management. General data management is concerned with general data identification that can fit any design problem. Designers can identify general data for the design problem under consideration to be used later to identify the specific data for the same problem. This total management of data allows the system to be used for various design problems' types since any relative data can be identified easily and immediately to suit that specific situation by the designers themselves without any amendments in the system's structure.

The specific data management class utilizes the previously identified general data to identify new specific data related to the design problem situation. It relates the identified features (functions, behaviours, and structures) with the identified products, components, and items. This data management class provides the base for the design knowledge representation structured at later stages in the developed CDT system.

2.2 Creative tools

The (CDT) system incorporates various creative design tools which were recognized for their usefulness in the production of creative design solutions. Each tool has its own ways of supporting the design team in their creative design tasks. The major common feature is their visualisation abilities in sharing the same design knowledge representation. The capabilities of the incorporated creative tools are discussed in the following sections.

Brainstorming

Brainstorming is a conventional tool for creative thinking based on generating a large number of ideas in limited time sessions, where no criticism is allowed and crazy idea are welcomed. The developed brainstorming tool's theme in the CDT framework provided a variety of procedures to generate ideas namely: brainwriting, brainsketching, and brainrelating without short time limits sessions. The generated concepts are stored in the temporary active project database for later reviewing and sharing. The sharing takes place after the sessions are ended. A selection is made based on the evaluation results to proceed with the chosen concepts.

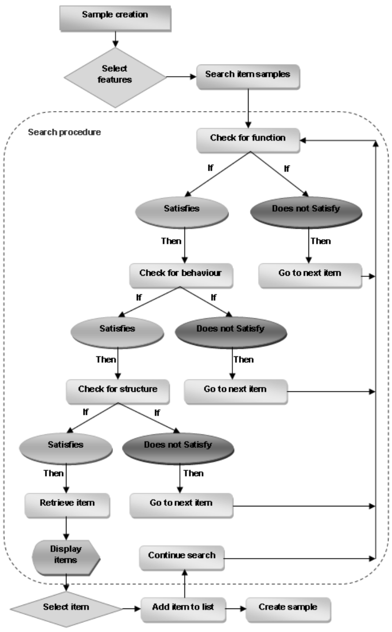

Figure 3: Sample creation procedures.

Concept mapping

The theme behind concept mapping is to externalise concepts and visualise them simultaneously. Concept mapping tool in the CDT system provides designers with an interface to structure concept's knowledge, store it in the databases, and link it to various file types. This tool takes into consideration the hierarchical structure of design knowledge throughout the identification of various components, items, functions, behaviours, and structures of each concept. This tool can be used to create new maps or retrieve existing ones. The produced design representation can be used by all other incorporated tools.

Analogy

Analogy can be defined as finding solutions applied at similar situations but in other domains. The analogy tool developed and incorporated in the CDT system has been designed to assist designers in exploring more design solutions where emergence of creative ideas can be recognized using analogical recognition of similar situations in other design domains. The developed tool has two main procedures which are: matching and retrieval, and mapping.

Matching and retrieval is concerned with searching for solutions that match the existing situation of the problem. The situation of the problem is formed at the early stages of preparation where functions, behaviours, and structures of the problem under consideration are identified. The matching and retrieval of analogical options are based on these previously identified features. The retrieved results may have interesting results which can be selected to perform the second procedure which is mapping. The proposed matching and retrieval alternative procedures are detailed as follows:

$$SIM (Fn_T, Fn_S (i)) = max_k SIM (Fn_T, Fn_S (k)) \quad (1)$$

$$SIM (B_T, B_S (i)) = max_k SIM (B_T, B_S (k)) \quad (2)$$

$$SIM (S_T, S_S (i)) = max_k SIM (S_T, S_S (k)) \quad (3)$$

$$SIM [(Fn_T, Fn_S (i)) \cup (B_T, B_S (i))] = max_k SIM [(Fn_T, Fn_S (k)) \cup (B_T, B_S (k))] \quad (4)$$

$$SIM [(Fn_T, Fn_S (i)) \cup (S_T, S_S (i))] = max_k SIM [(Fn_T, Fn_S (k)) \cup (S_T, S_S (k))] \quad (5)$$

$$SIM [(B_T, B_S (i)) \cup (S_T, S_S (i))] = max_k SIM [(B_T, B_S (k)) \cup (S_T, S_S (k))] \quad (6)$$

$$SIM [(Fn_T, Fn_S (i)) \cup (B_T, B_S (i)) \cup (S_T, S_S (i))] = max_k SIM [(Fn_T, Fn_S (k)) \cup (B_T, B_S (k)) \cup (S_T, S_S (k))] \quad (7)$$

where SIM (*,*) is a real function which measures the degree of similarity between its parameter spaces, Fn_T is the target function space, $Fn_S (i)$ is the i-th source function space, B_T is the target behaviour space, $B_S (i)$ is the i-th source behaviour space, S_T is the target structure space, $S_S (i)$ is the i-th source structure space.

The mapping procedure is to fit the retrieved options with the generated concepts to satisfy the design problem's goals, and requirements in that specific situation. The mapping can be conducted at any level in the hierarchical structure of the design concepts. It can be at the components, items, or features' level. The proposed mapping procedures are detailed as follows:

$$D^m = Fn^m \cup B^m \cup S^m \quad (8)$$

$$Fn^m = \tau (Fn_T \cup M (Fn_S (i))) \quad (9)$$

$$B^m = \tau (B_T \cup M (B_S (i))) \quad (10)$$

$$S^m = \tau (S_T \cup M (S_S (i))) \quad (11)$$

where M is a mapping operation, τ is a transformation operator, D^m is the modified design space, Fn^m is the modified function space, B^m is the modified behaviour space, and S^m is the modified structure space

Combination

The combination of two different ideas to come up with a new one is the main concept behind this tool. This concept of combination is valid to be applied even on the most complex products. Therefore, the developed combination tool incorporated in the CDT system took into consideration the complexity of products it can be applied to. Combination can be conducted at various levels of the product's hierarchical structure such as the whole products' level, components, items, or features.

Four combination methods have been developed and incorporated within the tool to combine options from the newly generated concepts and the already existing ones in the database. These methods are presented computationally as follows:

- Systematic Combination

$$\{ \{ u_{ij} \} \}_{j=1 \, i=1}^{n \;\; k} \quad (12)$$

where n = number of vertices in each tree
k=number of trees.

- Tree Random Combination

$$\{ \{ v_{g(i)j} \} \}_{j=1 \, i=1}^{n \;\; k} \quad (13)$$

where g is a permutation on {1, 2, 3,…k}

** (choosing the trees randomly)

- Vertices Random Combination

$$\{ \{ v_{if(j)} \}_{j=1 \, i=1}^{n \;\; k} \quad (14)$$

where f is a permutation on {1, 2, 3,…, n}

** (choosing the vertices randomly)

- Total Random Combination

$$\{ \{ v_{g(i)f(j)} \} \}_{j=1 \, i=1}^{n \;\; k} \quad (15)$$

where g is a permutation on {1, 2, 3,…, k}
f is a permutation on {1, 2, 3,…, n}

** (choosing the trees and vertices randomly)

Evolution

Evolution theme is based on generating new solutions using two or more parents. It usually incorporates two procedures; the first is cross over where different parts of both parents are crossed over between them to create new generations, the second is the mutation where some parts are altered to fit the boundaries of the situation under consideration. These two procedures have been improved to conduct its methods on the developed hierarchical design knowledge representation developed in the CDT system.

- The cross over procedure can be conducted at various levels and is modelled as follows:

$$S_{new1} = [S_{parent1} - \acute{S}_{parent1}] \cup \acute{S}_{parent2} \quad (16)$$

$$S_{new2} = [S_{parent2} - \acute{S}_{parent2}] \cup \acute{S}_{parent1} \quad (17)$$

$$Fn_{new1} = [Fn_{parent1} - F\acute{n}_{parent1}] \cup F\acute{n}_{parent2} \quad (18)$$

$$Fn_{new2} = [Fn_{parent2} - F\acute{n}_{parent2}] \cup F\acute{n}_{parent1} \quad (19)$$

$$Bh_{new1} = [Bh_{parent1} - B\hat{h}_{parent1}] \cup B\hat{h}_{parent2} \quad (20)$$

$$Bh_{new2} = [Bh_{parent2} - B\hat{h}_{parent2}] \cup B\hat{h}_{parent1} \quad (21)$$

where $\acute{S}$ is part of the structure, S is the whole structure, $F\acute{n}$ is part of the function, Fn is all the functions, $B\hat{h}$ is part of the behavior, and Bh is all the behaviors.

- Mutation is the alteration of one or more feature variables by an external process and is modeled as follows:

$$Fn_{new} = \Phi_m (Fn_{existing}) \quad (22)$$

$$B_{new} = \Phi_m (B_{existing}) \quad (23)$$

$$S_{new} = \Phi_m (S_{existing}) \quad (24)$$

where Φ_m is a transformation operator, Fn is the function of an object, B is the behaviour of an object, and S is the structure of an object.

2.3 Design modules

The CDT proposed system is composed of five major modules taking into consideration the systematic design process. Each module of them has several processes to be conducted by the design team and different tools which can assist the design process.

Preparation module

Problem definition seeks answers to many various questions, which in turn should establish key characteristics of the problem which are: the problem goals, the problem space (requirements), and the problem constraints. The proposed preparation module provides essential procedures to explore and define the design problem, specify requirements, and search existing solutions. These procedures are: client's meeting, problem formulation, search, analysis, synthesis, and problem reformulation.

Concept generation module

The concept generation module activates the application of the different incorporated creative thinking tools to generate and explore more creative concepts. In this module the design team members are encouraged to generate as many preliminary concepts as possible, share their generated concepts, explore supplementary concepts beyond the design problem space, and use divergence-convergence techniques to expand and reduce the solution space to select the most appropriate ones.

Development module

Development of the generated and selected concepts focuses on enhancing the selected concepts taking into consideration various vital issues. This enhancement needs to be documented to present a comprehensive reference for the manufacturing process, future amendments, and the creation of new designs. In the CDT development module two major procedures have been developed namely: enhancement, and documentation.

Evaluation module

The evaluation module in the CDT system is designed to be used at any stage of the design process. Evaluation is required to select the suitable concepts for future development. The process of evaluation has been divided into three correlated stages. The first stage is conducted at the level of individuals where each designer evaluates the generated concepts and saves the evaluation results for retrieval at later stages. The second stage is team evaluation. It is achieved by calculating the average of individual's evaluation scores to get the team's evaluation score. The third stage is the society evaluation by specialists other than the design team such as customers, other department's personnel, investors, suppliers and any other category of the society. This stage of evaluation explores how others view the design alternatives and if they are creative to them or not. A multi criterion has been used in the CDT system to evaluate design alternatives. In order for a design to be creative certain objectives should be met. The two major objectives are appropriateness and novelty.

Detailed design module

Detailed design module involves the production of the final specifications, CAD drawings, and 3D models. This module has been supported in the developed CDT system by incorporating CAD and word processing applications to facilitate the creation of these detailed documents for the manufacturing process.

2.4 User-friendly interface

The CDT system user interface was designed with a major aim in mind (*ease of use*). In terms of the proposed system navigation, a tree view navigation scheme is employed to provide immediate access to major tools and modules of the CDT system. The tree view nodes provide quick access to all parts, expandability, and holistic view of the system structural parts in one glance. Various visualization formats and presentations of information such as graphical, tabular, verbal, and written communications were used.

Several techniques have been applied in the developed CDT system to minimize the learning time of users such as tool tips and help windows. Furthermore, different types of users' input validation tools have been incorporated such as required fields validates, range validates, and compare validates to eliminate any conflicts by entering the wrong data.

In terms of the UI aesthetics, design principles have been utilized in a balanced manner to get the best out of the system's layout. Variety can be also recognized in the developed CDT user interface to prevent boredom but on the same time not to cause confusion to the users.

3 IMPLEMENTATION AND APPLICATION OF THE CDT SYSTEM

The developed CDT system has been implemented using Microsoft's ASP.NET web programming technology. This technology provided an easy platform to achieve the creation of data driven dynamic web applications with the minimal effort compared to other available technologies. The application of web-based technologies in design systems has several advantages. It overcomes the geographic factors between designers through its easy accessibility and the consistency of design knowledge it provides. Web applications provide the same experience for all users. Furthermore, the updates of the applications are reflected to all users which will minimize the administration time and cost of such applications updates. Any changes in the data are reflected immediately to all users at any locations which should enhance collaboration among design team members.

3.1 System scenario

The CDT system scenario detailed in Figure 4 starts by defining the design problem space through applying various activities such as meeting clients and conducting relative searches. This includes identification of the problem's goals, requirements, and constraints. This defined problem space can be modified each time a new knowledge evolves to adjust the problem's situation. Identification of new design knowledge is usually conducted by the design team in two stages. The first stage is at the preparation module where designers identify general and specific knowledge for the design problem to support its situation. The second stage is at the concept generation module when the designers start generating and exploring more design concepts. Designers are provided with the proper means to identify and store new knowledge in the incorporated databases, which in turn, can be part of the design problem situation and can be utilized by all the integrated elements of the system.

The generation and exploration of design concepts starts with the concept generation. Two divergent-convergent thinking approaches have been developed and implemented in this module. The generation of design concepts has been developed to apply a single divergent-convergent thinking approach at first using brainstorming and concept mapping tools. Designers brainstorm to generate as many concepts as possible individually without any criticism or evaluation of any sort. These generated concepts are structured hierarchically through the application of the concept mapping tool. At later stages, the designers evaluate the generated concepts of all the design team members to select the most suitable ones for exploration.

A multiple divergent-convergent thinking approach is applied through the exploration stage. Analogy, combination, and evolution tools are the active tools at this exploration activity. The designer chooses the methods to apply in each tool and selects the design concepts to use for exploration. Each time results are displayed, the designer selects few options to proceed with the same tool or to activate another tool. Therefore, it may take several iterations using the same tool to reach creative design concepts which are appropriate and novel.

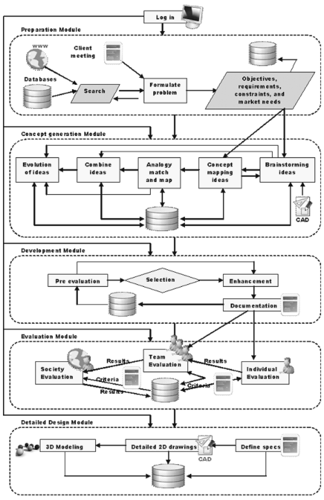

Figure 4: CDT system scenario.

3.2 Design knowledge implementation

The developed design knowledge representation described earlier is implemented using the tree view control in the ASP.NET environment which is connected to the databases or SQL documents. Each node in the tree is related to a certain field in a specific table in the database. Designers at the early stages of the design process can view and update data using the general data grid views. Further in the design process where more concepts are generated the tree view structure is used because it provides a wider scope of the design problem taking into consideration the various design details. The knowledge identification focused activity is divided into two major stages. The first stage involves general and specific data management while the second involves the preparation for the design problem under consideration. Both stages are conducted by designers to identify knowledge which is relative to the design problem under consideration.

3.3 Creative tools implementation

Each incorporated creative tool has a unique implementation scheme, although they all share the same design knowledge representation format. Various data web controls have been used to display design knowledge in the different tools such as GridView, DetailsView, and TreeView controls. Drop down list controls have also been used to display the options available for the designer to choose from. Furthermore, ordinary text buttons, and image buttons have been provided to implement certain functionalities.

The features identified at the early stages of data management can be used to apply constraints on the solution design space. A certain value for the function constraint can retrieve certain alternatives from the database with that specific function. If the search is for a component which function is heating, then alternatives which have this function are retrieved. Therefore, this limits the design solution space according to the constraints applied by the designer. This approach of implementing the constraints tactic is very flexible and constraints can be relaxed or tightened as required.

3.4 Case study

The case study starts with the initial design data management and sharing of basic design information which formulates the base for the preparation stage where the problem is formulated and more specific requirements and constraints are identified. Afterwards, through the use of various incorporated creative tools, design alternatives are generated and explored. Evaluation is conducted to validate and select the most creative ideas for development. The creation of new features (functions, behaviours, and structures) for the refrigerator has been chosen for representation. The refrigerator product has been explored in the case study and a hierarchical structure has been represented and used by the incorporated tools of the developed system.

Stage one: Design data management and sharing

General data management includes the design domains, products, components, items, and features such as behaviours, functions, structure categories, and structure category items. Product design problems can belong to different domains such as electronics, furniture, mechanical, kitchen appliances and many others. Each design domain includes many specific products. Kitchen appliances for example includes, refrigerators, freezers, ovens, hobs, washing machines, tumble driers, dish washers and many other small appliances such as coffee makers or toasters.

Specific data management is concerned with integrating the proper predefined features with the related predefined products, components, and items. In the case study demonstrated various functions have been defined such as cools, controls, stores, and many others. The behaviours reflect the characteristics of various components such as easy to use, easy to clean, saves energy and so on. The structure categories are the major structural features such as style, colour, size, shape, and material, while the structure category items are specific items of those structural features. Those identified specific features for each defined object are used later as constraints in the developed system to retrieve objects with specific features.

Stage two: Design preparation

Several processes constitute the major structures of this stage which are: client's meeting, problem formulation/reformulation, and search. Client's meetings provide the basis that the design team build upon the problem requirements, constraints, objectives and any other issues related to the problem. The meetings' details are stored in the database and reflected to all design team members to be retrieved when needed by design team members. The identified problem of the case study was to design a refrigerator with new functionalities and behaviours through the use of advanced new technologies which can service the requirements of modern kitchens and enhance the activities undertaken in such a busy zone of the house.

Designers search for data and information related to the design problem. They can retrieve sample solutions from the databases, based on specific features' constraints related to the problem. Relevant and useful retrieved data is stored in the active project database to assist the generation of conceptual design solutions. Furthermore, more searches can be conducted using the World Wide Web (WWW) or any other resources.

Stage three: Concept generation

The generation of ideas starts usually by brainstorming tool to let the designers generate many abstract alternatives to be considered. The generated ideas are stored in the active project database. The stored ideas can be retrieved by team members to select the most creative ones to develop. The ideas are displayed in a matrix form where each designer can enter his evaluation scale for the identified evaluation criteria built from the design problem requirements. Figure 5 shows a snap shot of the brainstorming tool.

Concept mapping is used to create the tree hierarchy structure for the selected ideas in order to be able to apply the other creative tools namely: combination and evolution.

Analogy matching and retrieval is used to retrieve more options from the stored design samples in the databases. The parameters used for this technique are the functions, behaviors, and structures already stored in the active design problem. The system displays these features for designers to select their preferred parameter to start the process as illustrated in Figure 6. These parameters are different for each design problem and reflect the type of problem under consideration. The results are displayed and few options are chosen to conduct the mapping techniques.

Combination methods are also provided for the designer to choose the preferred one to conduct some combination iterations on the tree structures of the selected options. Furthermore the evolutionary cross over and mutation methods are used to explore more options. The results are displayed and the creative ones are selected and stored.

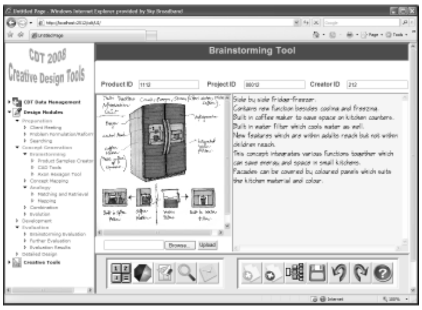

Figure 5: Brainstorming window.

Stage four: Design evaluation

After brainstorming, evaluation is used to rank the most creative options to be used for exploration of more design options. Furthermore, after more options are explored and some ideas are developed, evaluation is used to choose the most creative ideas for detailing. Design evaluation stage has been implemented in the CDT system based on three levels: the individual, the team, and the society. Individual designers can view the stored ideas and evaluate those ideas via two part criteria: appropriateness, and novelty.

The designers give scores to the design options using a scale from one to ten where one is the least creative idea and ten is the most creative one. The evaluation result for each design idea is stored in the database and associated with the idea data and the individual designer whom evaluation is stored.

Figure 6: Analogy matching and retrieval.

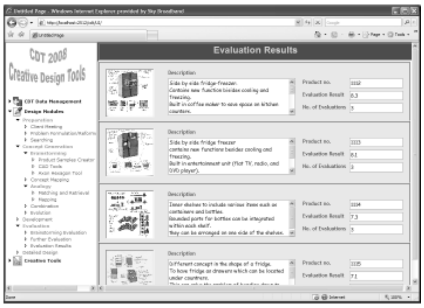

Figure 7: Evaluation results.

4 CONCLUSIONS

A holistic approach for enhancing creative design thinking through the conceptual design phase has been presented in this research paper. The integration of various creative tools within a shared design environment facilitates collaboration among design team members to produce more creative ideas, evaluate them, and select the most appropriate ones to be developed and detailed for production. The early evaluation of design concepts minimizes the lead time for industry since the inappropriate ideas are eliminated early in the design process. Therefore, reductions in conflicts and inconsistencies at later design stages are achievable and the production of more creative ideas is viable. The system has shown an innovative approach to integrate several factors which affect creative design thinking namely: distributed design team members, design knowledge representation, creative thinking tools, and design processes.

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