A systematical multi-professional collaboration approach via MEC and morphological analysis for product concept development

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Abstract. In this article, a systematical approach that attempts to integrate conventional quality function deployment (QFD) and morphological analysis in terms of effective multi-professional collaboration (MPC) knowledge handling in product concept development is presented and illustrated. For this purpose, a MPC-enabled product conceptualization paradigm was established. It consists of four scrupulously interacting modules, namely, user needs elicitation module using means-end chain (MEC) technique, design knowledge interaction module using design knowledge sharing model, product concept clarification module integrating QFD with functional analysis technique, and optimal concept alternative module using multi-attribute evaluation model (MAEM) within morphological analysis. A case study on the design of eating assistive device for patients with cervical cord injuries is used to demonstrate the performance of the proposed approach. From the case study, the authors also illustrate the effectiveness of concept design prototype with remote collaborative product design communication platform and rapid prototyping system which were applied in collaboration.

Keywords. Multi-professional collaboration, Product concept development, Means-end chain, QFD, Eating assistive device

1 Introduction

To develop an innovative product, it is even more critical to know the needs of the consumer. The designer need to acquire the knowledge on the user's specific requirements and marketing strategies and then integrate all of the information into a distinct design which differentiates competing products from each other.

User-oriented assistive device development is a usability-based innovation concept, which focuses on the use of disabled patients' current and future needs, as well as their characteristics, in the design of innovative and/or improved assistive products. Consequently, to develop a successful eating assistive device for patients with cervical cord injuries, user requirements need to be carefully considered by implementing the multi-professional collaboration approach during product conceptualization. The key phases in the expression of this concept are:

requirement identification, knowledge synthesis and idea creation to fulfil the need, product development to substantiate the idea and the user's need, and verifying the fulfilment of the need.

Central here is the systematic approach to interpret the subjective and implicit consumer needs (e.g. functionality, usability, aesthetic sensibility and values, etc.) into objective and explicit product conceptualization, in order to, through the creation of the distinctive and superior product, substantiate the fulfilment of these needs. For this purpose, a MPC-enabled product conceptualization paradigm was established. It consists of four scrupulously interacting modules as shown below:

1. User needs elicitation module using means-end chain (MEC) technique for requirement identification.
2. Design knowledge representation module using design knowledge sharing model for knowledge synthesis and idea creation.
3. Product conceptualization module integrating QFD with functional analysis technique for product development to substantiate the idea and the user's need.
4. Optimal concept alternative module using multi-attribute evaluation model (MAEM) within morphological analysis for verification.

A case study on the product concept development (PCD) of eating assistive device for patients with cervical cord injuries is used to demonstrate the performance of the proposed systematic approach. From the case study, the authors also illustrate the effectiveness of concept design paradigm with remote collaborative product design communication platform and rapid prototyping system which were manipulated in collaboration.

2 Related works

It is well known that assistive devices can help disabled persons become more independent and increase their quality of life. However, there are many differences between the disabled persons' conditions as well as due to the limited amount of available assistive devices. Generally, seriously disabled persons haven't yet had access to the functionality of assistive devices. For example, patients with cervical cord injuries have two types of eating assistive devices to choose from; one is an expensive, power-controlled device that is unsuitable for patients with a serious cervical cord injury, while the other involves feeding via a caregiver. In order to develop an eating assistive device that can be used by a patient with a serious cervical cord injury independently, it is important to construct a systematic approach that integrates the MPC knowledge and information technology support system for implementation the requirement identification, knowledge synthesis and idea creation to fulfil the need.

2.1 User needs elicitation module and MEC

Products or services are usually presented in terms of their attributes, such as functionality, usability, quality and aesthetic sensibility. Although the consequences of using them are affected by the end user, these attributes may be related to the realization of personal values and emotional situation. In general, consumer needs start the early stage of new product development process, and the determination of correct and complete information requirements sets the stage for an effective development process that increases the likelihood of satisfaction in the implementation and allows for early correction of errors while the cost is lower [1]. One of the primary goals of the collection and adoption of user needs information in new PCD is the identification of customer preferences [2]. In order to deal with the task, a MEC approach is used to identify the attributes, consequences and values perceived by the user. Since its introduction into the marketing literature by Reynolds and Gutman [3], MEC has become a frequently-used qualitative technique in formulating the strategy of product development and marketing promotion in many fields.

An MEC methodology illustrates the connections between product attributes, the consequences or benefits of using product and personal values; A-C-V structure (Figure 1), where the means is the product and the end is the desired value state. The purpose of the MEC theory is to explain how product preference and choice is related to the achievement of central life values [3].

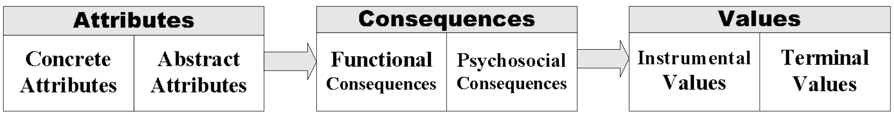

Fig. 1. MEC via A-C-V structure of user's product percipience

Integrated with the data-collection technique called laddering, it was proposed by Reynolds and Gutman [4], which is implemented in-depth, one-on-one interviewing process for eliciting A-C-V linkages from consumers for revealing the structure of MEC. Laddering is able to lead consumers to clearly communicate their inner important attributes, consequences and values and then form the structure of MEC, which are put into a hierarchical value map (HVM) (Figure 2), depicting the cognitive or motivational decision structure of the consumer [5]. An HVM is gradually built up by connecting all the chains that are formed by selecting the linkages whose values in the implication matrix are at or above the cutoff value.

The laddering technique consists of three phases:

1. elicitation of crucial attributes, It is usually followed by the Kelly Repertory Grid technique or the rank ordering method to record and analyze the entire set of laddering across respondents for classifying the relation between the constructs and organizing them into hierarchical relations [4,6,7].
2. laddering depth-interviews. This is a one-on-one interviewing technique, using primarily a series of directed probes and a series of "Why is this important to you" questions that produce the following ladder [8]:
   Aircraft type ->more space ->physical comfort ->get more done -> accomplishment ->self esteem
3. analysis of results. In this phase content analysis is used to categorize the idiosyncratic responses into a smaller number of categories. Subsequently, an implication matrix is constructed, which shows the links between the concepts in terms means and ends.

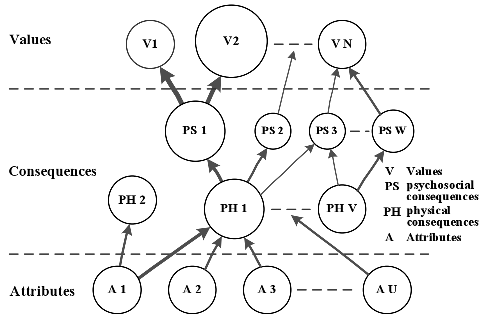

Fig. 2. Hierarchical value map for revealing the structure of MEC

2.2 Collaborative knowledge to support MPC

As the complexity of new product development processes increases, the designing process has to integrate a great number of expertises who are based on the collaboration between the different types of challenges.

To increase design performances and consequently to satisfy customers' requirements and expectations, the decision-makers (generally the project managers) have to adapt the designers' work-context to the environment of the design process. The work-context of the performers will be improved and, when the project manager will be able to create effective working group according to the design objectives, human resources allocation will be more efficient.

Knowledge of the actors refers to all their expertises in one or several given domains and could be defined as being at the crossroads of in-depth knowledge and collaborative knowledge. Rose et al. [9] proposed to structure this knowledge in four different types (Figure 3):

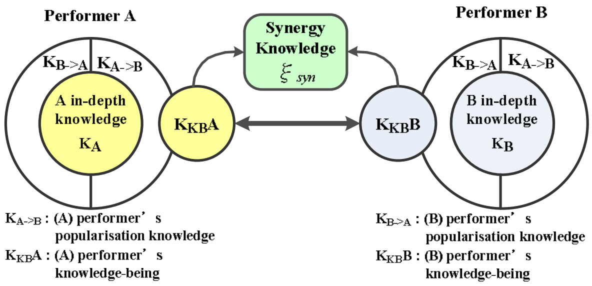

Fig. 3. Knowledge shared during collaborative design process [9]

- Popularization knowledge is acquired by the performer, coming from the other members of the design team.
- Popularisation knowledge is distributed to the other performers of the design project. It is a support of the problem solving.
- Knowledge is used by each performer when he or she has to initiate communication with the other performers. It can be seen as interface ports to reach other performers of the surrounding context.

- Synergy knowledge, implemented to carry out and maintain the intra-team knowledge exchanges. It's a support of communication.

2.3 QFD with functional analysis

By employing the QFD method, the consumer needs are systematically matched with the product attributes, which can help MPC team members to improve the product development quality. For this purpose, QFD has been widely studied and applied to transfer the consumer needs and wants into the design process and product attributes by systematically letting the wishes are reflected at every stage of the product development process.

In the QFD analysis, a matrix is used, called the relationship matrix, where the analysis is carried under the mapping from requirement attributes into design components. In order to get this information for the MPC approach, the user needs and their rankings are determined through the MEC-analysis and interviewing survey, in which the values 9, 5, 3, 1, and 0 indicate the mapping relationships ranging from very strong, strong, ordinary, weak, and none, respectively. Finally the overall weights of the product attributes are calculated and then the product attributes corresponding to the user needs' differentiations are listed and the relationships between user needs and product attributes are established. The result obtained from QFD is incorporated into the HVM graph to identify the PCD component to be developed with the morphological analysis, deriving new products that satisfy user needs by designing finite components.

The QFD used in this study is modified in the way that the technical analysis and competitor analysis are not carried out, thus the relationship matrix only lists the importance of the differential product attributes.

2.4 Morphological analysis with MAEM

Morphological analysis (MA) was developed by Fritz Zwicky as a method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem where causal modeling and simulation do not function well or at all. [10]. More recently, MA has been applied by a number of researchers in the fields of policy analysis and futures studies. Owing to the advanced computer support system for MA was developed that has made it possible to create non-quantified inference models, which significantly extends MA's functionality and areas of application [11].

For promoting the innovative design, a morphological chart is presented as a visual way to acquire the necessary product functionality and explore alternative means and combinations of achieving that functionality. It is one of the formal design tools enabling collaborative product development and is also an effective technique for conceptual design of products, processes, and systems [12]. In practice and in academia, the product development team can use the morphological chart to identify sub-systems and their alternative components, implementation techniques etc. for examining and figuring out systematically a number of variant but equivalent design entities and to help widen the search for solutions of the original PCD.

As a result of generating a lot of solutions from morphological chart, the designer has to verify and sieve out the relevant or practical combinations of product functionality from the solution pool. In order to evaluate the alternative concepts presented in the previous section, it is necessary to define a number of variables (cost, ease of implement, functionality etc.) that will be used in the MAEM process.

Simple multi-attribute rating technique (SMART) is an extension of direct rating technique [13], one of the MAEM methods, and is suitable to be applied to verify the alternative PCD solutions which were generated by MA. In a basic design of SMART, there is a rank-ordering of alternatives for each attribute setting the best to 100 and the worst to zero and interpolating in between. By refining the performance values with relative weights, a utility value for each alternative is calculated. In SMART, the formula for a weighted average is simply given as follows: $U_i = \sum_j w_j u_{ij}$,subject to $\sum_j w_j = 1$, where U_i is the aggregate utility for the ith alternative, $\boldsymbol{w_j}$ is the normalised importance weight of the jth attribute of value and $\boldsymbol{u_{ij}}$ is the normalised value of the ith alternative on the jth attribute. In general, the U_i for the ith alternative is provided with the highest weighted average ranking value will be defined as the optimal solution. It means that the goal is Max $U_i = \sum_j w_j u_{ij}$ [14].

3 Modeling the MPC-enabled PCD paradigm

The MPC approach presented in this paper focuses on the user centred design side and the concept development phase, where consumer needs and product attributes have to be defined and interpreted for PCD. In Figure 4 the authors illustrate a framework which is integrated with multiple modules in pursuit of the study goal.

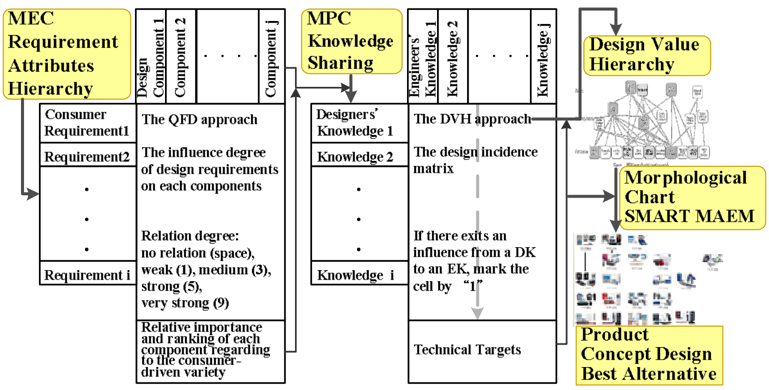

Fig. 4. Framework of the MPC-enabled product conceptualization paradigm

From a multi-professional knowledge-integrating viewpoint, the proposed model comprises four correlated modules and four main stages. The first stage begins with consumer needs elicitation using MEC technique, which clarifies the variant attributes and values of users. The second stage consists of the knowledge sharing model and QFD analysis, during which the variant attributes with involved knowledge are related to design components with specific values to identify relationship degree, thus yielding the relative importance of each component towards the differential product attributes. In the third stage, the solution pool of PCD is produced from MA and the optimal solution is verified with SMART of MAEM. Finally, the result obtained from the MPC approach is incorporated into the product usability experiment to derive the satisfaction with finite revision.

4 Use of MPC for PDC of assistive devices

This investigation involved the development of eating assistive devices for patients with cervical cord injuries, which was based on the collaboration of physiatrists, designers, marketers and heavy disabled persons.

A depth-interviews was conducted with 28 subjects, C4 to C6 cord injuries, between 20 to 56 years of age who had been hospitalized rehabilitation and been served with eating assistive devices. Subjects were asked to express the degree of importance of attributes and indicated the most important one and then multiple chains were acquired per respondent for the evaluation variables of the concerned phases-functions, explicit features, operating method, technology and aesthetic sensibility about the product. Using laddering method answers were divided into attributes, consequences, and values and categorized further using with summary implication matrix (Table 1). The absolute number of concepts and the number of linkages between concepts was counted to construct the HVM (Figure 5).

Table 1Summary implication matrix

Code	01	02	03	04	05	06	07	08	09	10	11	12
01	3.0 0			4 00		0.0 1	0.0 1		0.0 1	0.0 1	0.0 1	0.0 1
02						2.0 0	1.0 0				0.0 1	0.0 1
03				1. 00		0.0 1					0.0 1	
04				2. 00		0.0 1	0.0 1		0.0 1	0.0 1	0.0 1	0.0 1
05						3.0 1	0.0 1		0.0 1	0.0 1	0.0 1	0.0 3
06									5.0 0	0.0 3		
07							5.0 0				0.0 4	0.0 4
08											5.0 4	0.0 4
09										2.0 0		
10										10 5		
11												
12												5.0 0

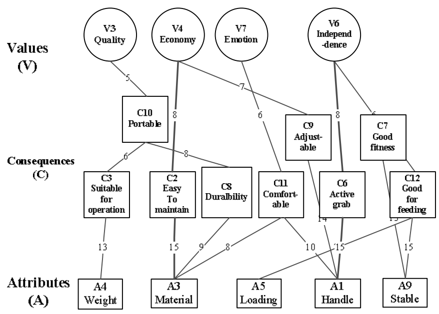

Fig. 5. HVM of eating assistive devices

5 Conclusions

Table 2 demostrates that the differential importances of components for the PCD of eating assistive device which must satisfy the need of feeding independently.

Table 2 QFD matrix for mapping the differential needs of manipulation into components

Usability differentiation need	Component											
	Linkage	Handle frame	Handle	Spoon	Fork	Tray	Bowl	Bowl cover	Cup	Cup frame	mat	Box
Feeding independent	5	9	3	5	3	3	9	3	3	5	5	1

According to the results of MEC and QFD analyses, MPC team members used the MC technique with CAD and collaborative communication systems to develop the PCD which was transferred to prototype and verified by the subjects.

The best alternative of PCD is finalized from MC with SMART process and presented as following (Figure 6) :

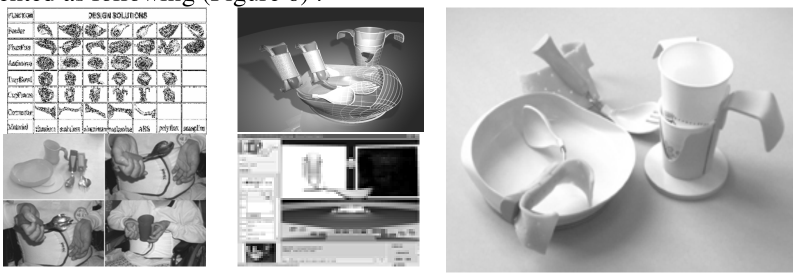

Fig. 6 The optimal PCD of eating assistive device

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