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MANAGING COMPLEXITY IN USER EXPERIENCE DESIGN: MATRIX-BASED METHODS FOR CONNECTING TECHNOLOGIES AND USER NEEDS

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1. Introduction

Products are becoming increasingly complex, due to a variety of reasons: new technologies, novel interfaces, multi-functionality, use in dynamic situations [Bijl-Brouwer and Voort 2008] and combination with other products and services. This trend roots in the users´ actual need for complex tools to face complex tasks in complex environments. Therefore tools with dense features which help users accomplish their tasks are preferred to simple ones [Norman 2010].
The challenge when designing lies in eliminating the *perceived* complexity, the confusion and frustration caused to users by poor design, and providing an enjoyable overall user experience (UX). The desired property is not simplicity in terms of minimalism, but in terms of comprehensibility and order – as stated by Apple Inc. [2013] "It´s about offering up the right things, in the right place, right when you need them: bringing order to complexity". Designers should ensure that their solutions are understandable, usable, and enjoyable, and provide the complexity users need in a manner that is understandable and elegant [Norman 2010]. To achieve this goal, applicable methods to manage complexity and consider experience-related factors are needed.
Matrix-based methods are widely used for complexity management in many applications, but are not yet considered for deliberate application in user experience design (UXD). This paper introduces a matrix-based methodology adapted to the needs of UXD projects. Goal is to build up function clusters and consider their integration into one new interface. The focus lies on integrating functions from a user-centred vs. technology/component-centred perspective.
The study presented in this paper is based on literature review and actual method application within a three-year interdisciplinary UXD research project. The outcomes have been evaluated by UX experts, industry partners and within user studies.
The following section presents related work, while section 3 covers the description of the proposed methodological approach highlighted with an example. The paper ends with a discussion of the approach and an outlook on future research.

2. Background and objectives

2.1 UXD and complexity of UX

The research fields of UX and UXD focus on analysing the users' personal impression and on making the emotional impact of product solutions describable or even measurable. The approach of UX aims at developing experiences via the product usage, which has to meet psychological needs and motives of the user and fulfil or even exceed her/his expectations [Hassenzahl 2010]. Hassenzahl [2010] describes “be-goals” as a level of interaction crucial for UX, since they serve as motivation for an action and give it ultimate sense. An important requirements for high-quality UX is to meet the exact needs of the customer, without fuss or bother, but with simplicity and elegance that result in a joy to own and to use products [Nielsen and Norman 2012].

Roto et al. [2011] point out crucial characteristics of UX, such as its dynamic nature and temporal aspects. UX is dynamic as the person experiencing the system with its motivation, mood, its current mental and physical resources and expectations, is dynamic. Actual experience of usage does not cover all relevant UX concerns, since indirect experiences can appear before use or extend after usage. Additionally, UX may change when the context changes, even if the system itself does not change; relevant for UX can be social, physical, task, technical and information context.

Roto et al. suggest “system” and the user’s perception of the system’s properties as key factors influencing UX. Since products are components of larger systems, not only properties designed into the system, but the brand image and properties added or changed in the system play an important role.

Nielsen and Norman [2012] state that “UX encompasses all aspects of the end-user's interaction with the company, its services, and its products” and emphasises that “total UX” is a concept even broader than usability or a user interface, even though they are extremely important parts of the design as well.

Designing attractive products that evoke positive emotions requires knowledge about the feelings products arouse as well as knowledge about users and their needs. UXD is a user-centred process with user research and user evaluation being central elements. Furthermore, in order to achieve high-quality UX in a company's offerings there must be a seamless merging of the services of multiple disciplines [Nielsen and Norman 2012]. Engineering, marketing, graphical and industrial design, and interface design experts are asked to collaborate towards this goal.

To highlight the motivation for this research, *Figure 1* depicts on the right side a modern premium car: much more complex than the car of the 90ies shown at the left. The challenge is providing the multiple functionalities in an intuitive, but also enjoyable, for the driver way. Designing each system separately would not be enough to reach this goal: even if the functionality and user interface for each system is perfect, the total UX will be poor for a user who feels confused when facing an overloaded interior.

Figure 1. Car interiors are becoming increasingly complex

Summing up, the design of positive experiences requires a holistic understanding of “soft” aspects, such as user needs and motives beside product functions and characteristics. To create a positive total UX those aspects need to relate to each other harmoniously. Furthermore, UXD practice is user-centred and interdisciplinary and hence challenging to manage.

2.2 Matrix-based approaches

Matrix-based methods for system modelling and analysis are introduced by many researchers to manage the complexity of engineering systems and complex product design processes [Hauser and Clausing 1988], [Kusiak and Park 1990], [Eppinger 1991], [Yassine et al. 1999], [Browning 2001], [Yassine et al. 2001], [Eppinger and Salminen 2001], [Brady 2002], [Yassine 2004], [Danilovic and Börjesson 2011]. Lindemann et al. [2009] classified the matrix-based methods used in product development in four types of general matrix systems. According to the quantity of the types of elements involved and executed computations, matrices can be defined as “Dependency Structure Matrices” (DSM), “Domain Mapping Matrices” (DMM), combined intra- (DSM) and inter- (DMM) domain matrices, as well as “Multiple-Domain Matrices” (MDM).

2.2.1 Intra-domain matrices – DSM

If relations within elements belonging to the same type are examined the related matrices can be defined as intra-domain. Browning [2001] describes a DSM as a matrix with an equal number of rows and columns, in which elements – typically of only one system at a time – and their relationships are systematically mapped. A typical example is a matrix depicting dependencies between physical product components. The element names are placed down the side of the matrix as row headings and across the top as column headings in the same order. The diagonal elements of the matrix are normally not considered. Binary DSMs depict only the existence and the direction of the relationships, while numerical DSMs can describe values of attributes, such as importance ratings or the probability of repetition [Yassine et al. 2001], via the use of different marks in the cells, e.g., symbols, colours, or numerical rankings.

2.2.2 Inter-domain matrices – DMM

Matrices combining different elements belonging to different domains (e.g. customer requirements and product functions) are referred to as inter-domain matrices or “Domain Mapping Matrices” (DMM) [Danilovic and Börjesson 2001]. DMMs link elements of two different domains and are widely used in design methodology, for example in studies on linkages between product architecture and organization as well as between systems and organization.

2.2.3 Combined intra- and inter-domain matrices

Some applications make use of combinations of intra- and inter- domain matrices for more complex analysis possibilities, for example to implement a systematic comparison.

2.2.4 Combined intra- and inter- domain matrices with computations - MDM

If in addition to the combined use of intra- and inter-domain matrices, computations of some subsets by information stored in other subsets are also included, such an approach is called the Multiple-Domain Matrix (MDM). MDMs are based on DSM and DMM approaches but differ from the combined application of intra and inter-domain matrices by computations within the considered matrices [Maurer and Lindemann 2007].

Summing-up, matrix-based approaches are widely used for complexity management in many applications. The use of DSM has been extended to many types of system and design analysis in product development, project planning, project management, system engineering and organization design [Brady 2002]. DSM approaches have been successfully implemented in the fields of [Yassine 2004]: knowledge capturing, information transfer, understanding of products and processes, schedules and cost distributions, analysis of systems and products architectures. MDM approaches have further been used for managing different types of knowledge configuration and management of multi-project environments. These applications encourage the use of matrix-based approaches in UXD, but no research on this specific application is yet to be found.

2.3 Objectives

This work aims at introducing an approach to explore relations among UX elements and thus provide a better understanding and dealing with technologies, motives and needs. The targeted analysis of relations between user motives and functions via matrices is proposed to build user-centred function clusters. This user-centred approach goes beyond the conventional technology-oriented integration strategies or 1:1 mappings of functions to interface elements. These strategies are insufficient since they often lead to redundancies, large amount of buttons and displays being visible at any time and, in that way, high potential for leading to frustration of the user dealing with them. Our goal is to provide ideas for interfaces which are more understandable, of less perceived complexity and therefore more likely to contribute to better total UX.

Furthermore, the systematic approach contributes to better management of UXD processes; members of the UX team and relevant data are better involved in the process. The approach also aims at creating a traceable link between functions and needs addressed by them; in this way a basis for evaluation of total UX is provided. Different approaches within the method should enable its flexible, project-specific application.

3. Proposed method

In this section we introduce a matrix-based method to face the challenges of UXD. The UX-related domains and methods to collect needed data are described in 3.1, while important inter- and intra-domain relations are depicted in a meta-model in 3.2. Different approaches to proceed depending on the project goal are presented in 3.3. Finally, the method steps are described in 3.4.

3.1 Domains and data acquisition

The domains are selected by the authors as most relevant for UX, since they cover emotional, technical and temporal aspects of interaction (overview in *Table 1*).

Emotional factors are addressed by the domains “**need**” and “**motive**”. According to the definitions of UX presented in 2.1., fulfilment of needs and motives via product usage are a measure for UX quality. We recommend selecting an established set of psychological needs, like the ones presented by Sheldon et al. [2001]: competence, security, relatedness, popularity, physical thriving, money-luxury, self-esteem, autonomy, self-actualization, pleasure-stimulation. Creating and testing a new collection of needs and items to evaluate their fulfilment can be a time-consuming process with a strong focus on psychology and thus goes beyond the aims of this study. Motives, as representations of “be-goals” (i.e. the cause to perform an action), are more concrete than psychological needs and strongly dependant on the development object; their study is therefore recommended. They are results of intensive user research and can be collected directly from real users, e.g. within surveys and interviews, or indirectly, e.g. via social media analysis. Techniques recommended by the researchers are: laddering [Reynolds and Gutman 1988], storytelling [Michailidou et al. 2013b] and experience sampling [Kim et al. 2011], since they provide deeper user insights and help practitioners understand the underlying reasons of an interaction.

Temporal aspects are addressed in the domain “**use case**”. Situations before, during and after usage of the new product, are listed here. Cognitive walkthroughs [Polson et al. 1992], moderated workshops and targeted studies are recommended methods for use case selection. Structuring the use cases in a morphological case [Lindemann 2009] can help systemizing the findings.

Technical aspects are represented by the domain “**function**”. Different functionalities of the observed system are supposed to be listed here. Phrasing the function as “noun + verb” forces thinking about the “do-goals” [Hassenzahl 2010] rather than the “motor-goals” of an activity. Additionally, the use of function models and particularly hierarchical function models is highly recommended, as it helps practitioners decide for a common detail degree in the description.

One product can be used by different users for different purposes; this matter is considered in the domains “**market**” and “**user**”. In the “market”-domain representative customer profiles for relevant market segments are listed. This information is retrieved from production, sales and marketing data. The “user”-domain depicts more specific user data rooting in customer studies. Depending on the product category it may concern user characteristics, such as anthropometric data, or the user´s perspective, e.g. a system in the car has different effects when perceived from the perspective of co-driver or rear-seat passenger, of another driver, of first or second buyer of the car.

Table 1. Domains and data collection

Domain	*Method to collect data*
Need	Literature-based sets of needs

Motive	Surveys, interviews, laddering, customer feedback, social media analysis, storytelling, experience sampling
Use case	Moderated workshops, cognitive walkthrough, morphological case, studies
Function	Function modelling, product manuals, data loggers
Market	Production, sales and marketing data
User	Customer studies

3.2 Relations among domains

Even more important than collecting the elements for each domain and studying them as such, is thinking about the relations among them. The meta-model in *Figure 2* gives an overview of all domains and important relations among them.

	Function	Motive	Need	Use case	Market	User
Function	is mutually exclusive with	fulfils	satisfies	is used in	is demanded in (quantitatively)	
Motive		can occur at the same time with	meets	can occur at the same time with		
Need				is relevant in	is relevant in	
Use case	influences	stresses	stresses	can occur at the same time with	occurs in (quantitatively)	
Market			stresses the importance of			
User	steers	has	has	is affected by		

Figure 2. The meta-model shows how do the UX-domains relate to each other

Each relation represented in this model can be expanded as a DSM or DMM. At this point it can further be identified within which matrices computations could be considered.

3.3 Approaches

According to specific project goals, different approaches can be selected for further use of the matrices to create function clusters. Two exemplary approaches, the motive-based approach and the use case-based approach are introduced.

3.3.1 Motive-based function clustering

This approach is appropriate for creating clusters of functions addressing similar or related user motives. The clusters can then be further developed as one new device or interface element. This matching of functions is more likely to create a positive UX, since users´ motives are addressed by more than one functions and are therefore more likely to be fulfilled.

A good example for such a device is the driving mode button, depicted on the right side of *Figure 3*. Many manufacturers provide an interface element allowing users to select “sport” or “eco” modes. Each setup influences numerous car settings which contribute to the motives of “driving sporty” or “driving eco-friendly”. The systems affected are not visible to the driver; behind the “eco”-button there is a function cluster addressing the motive of driving eco-friendly. The description provided gives the driver all the information she/he needs. On the contrary, the functions Lane Change and Lane Departure Warning (depicted left) can be controlled by separate interfaces, despite addressing very similar motives; there is still the possibility of integrating them (and other functions) into one “avoid dangerous situations”-interface.

Figure 3. Two examples of mapping

First steps towards building motive-based clusters are selecting a motive “theme” and the psychological needs addressed by it. The goal is to find supplementary motives and define the criteria for the UX evaluation. Therefore, the “DSM_motive”, i.e. the matrix depicting the relation “Motive can occur at the same time with Motive”, and the “DMM_Motive-Need”, i.e. the matrix depicting the relation “Motive meets Need”, are analysed. By analysing the “DMM_Function-Motive”, the design team decides for each motive which function fulfils it. The functions selected in this step build a cluster, which can be further implemented as one new device. It can also be considered for the positioning of interface elements and even the creation of a new interface element. An overview of the process and relevant matrices is depicted in *Table 2*.

Table 2. Motive-based function clustering

Goal	*Relation to be analysed*	*Relevant matrices*
Select “theme” of motives (What is the cause to perform an action?)	“Motive can occur at the same time with motive”	DSM_motive
Set criteria for UX evaluation (Which needs are to be fulfilled via product usage?)	“Motive meets need”	DMM_Motive-Need
Explore functions to fulfil motive (Which functions build motive-based clusters?)	“Function fulfil motive”	DMM_Function-Motive
Create device/interface (How can the user control the functions?)	[This is the creative phase, based on the function clusters created through all the previous steps]	
Evaluate device/interface (Are the addressed needs fulfilled in the relevant use situation?)	“Motive fulfil need”, “Function is used in use case”	DMM_Motive-Need, DMM_Function-Use Case

The use of UX stories [Michailidou et al. 2013a] and metaphors can be helpful for understanding and communicating the “theme” of the cluster when exploring the relations and filling the matrices.

3.3.2 Use-case based clustering

This approach can be applied to face the problem of offering the right options when the user needs them. Functions which are more likely to appear in a use case build a cluster which appears in relevant situations. Not all functions must be present at all times. For example, when driving in a highway, parking assist functions are irrelevant. Making relevant options more present and/or letting irrelevant options fade away can eliminate the perceived complexity of a system and contribute to positive UX. Take the menu bar of Microsoft Word as an example: The options for formatting pictures appear once a picture is inserted or selected and only then. The process towards use case-based clustering builds on the motive-based approach. The difference is that only motives appearing in a selected use case are considered here.

3.4 Method overview

An overview of the suggested steps to apply the method are presented here:

3.4.1 Adjust meta-model

In the first step, the most relevant relations among the UX domains need to be identified. This is essential, because the method has to be applied in a flexible way , according to the focus and nature of each project. For example, for a product aiming at a local market, the consideration of other market segments and so the "market"-domain are irrelevant. The decision about which matrices will be filled out in the next steps can be based on the initial meta-model provided (*Table 2*) and should be made within the UX-team, with the guidance of a method expert.

3.4.2 Enter elements of relevant domains

In the next step, elements of the relevant domains need to be selected and entered into the matrices as tables and/or rows. Methods supporting the data collection are presented in the section 3.1. Again, the amount and level of detail of the data can differ in each project.

3.4.3 Define relations among elements

This step concerns the identification of relations in each of the selected matrices. The identification of a relation should be the result of discussion among members of the UX team. Outcomes of this step are the filled matrices and additional comments noted by the moderator.

3.4.4 Select approach to cluster

The last two steps concern the identification of related functionalities and their rearrangement in a new interface. Important is this step is the decision for a user- and experience- centred integration instead of a geometrical approach. Two approaches are discussed by the researches: use case-based (i.e. functions most likely to be needed in a use case are clustered) and motive-based (i.e. functions addressing similar motives are clustered).

3.4.5 Create interface concepts

Now the creative phase can begin; functions identified in the previous step, as related to each other in a comprehensible for the user way, can be integrated into a new interface.

4. Results

The method has been applied by the researchers within a research project. The overall project goal was the systematic creation and evaluation of UX in the context of electric mobility. The team, consisting of one psychologist, two engineers, one industrial designer, and one human factors expert, investigated, adapted and applied methods from all disciplines in a new development project. The project was supervised by UX experts and industrial partners, while the outcomes have also been evaluated within user studies.

The presented method was applied to support the integration of different functionalities into the car interior in an enjoyable and understandable way and resulted in the conception of a novel interaction device. Goal was to create a novel interface for the electric vehicle to enable the driver feel the status of his car. The focus lied on creating an enjoyable overall experience. Considering the extent of this paper, only some of the results, considered as most relevant for understanding the method, are presented in this section.

Firstly, following relations of the meta-model (*Fig. 2*) were selected as most relevant for the project:

- "motive can occur at the same time with motive", DSM_motive
- "motive meets need", DMM_Motive-Need
- "function fulfils motive", DMM_Function-Motive
- "function is used in use case", DMM_Function-Use case

In the next step, data for the selected domains (need, motive, use case, function) had to be selected and entered into the corresponding matrices. The needs selected were based on the needs tested by Sheldon

et al. and have been slightly adapted to better fit to the automotive context. More methods have been applied to select motives: qualitative, semi-structured, individual interviews with duration of about 30 minutes each, as well as qualitative extended interviews with a duration of 90-120 minutes each, have been conducted with drivers of electric vehicles. Storytelling has also been applied within moderated workshops [Michailidou et al. 2013b]. Use cases have not been collected by the researchers: the automobile company provided ca. 20 relevant use cases to be considered. Finally, the collection of functions has been supported by the creation of a hierarchical function model. About 60 different functions have been documented and the 20 most relevant have been selected, according to their relevance to electric mobility, their potential for positive experience creation and project restrictions (e.g. focus on car interior, no primer driving functions).
In the next step relations have been identified in each of the selected matrices (DSM_motive, DMM_Motive-Need, DMM_Function-Motive, DMM_Function-Use case). Each matrix has been filled out within moderated workshops with the researchers moderated the workshop as "method experts" and project partners with expertise in the topic discussed in each matrix invited as workshop participants. The identification of relations between motives or motives and needs, for instance, required the participation of psychologists, while matrices involving car functionalities required the attendance of technology/engineering experts. The workshop results were all documented in Excel tables in a compatible to LOOMEO™ format. The matrices have been imported to LOOMEO™, with an analysis and creation of graphs to follow. The matrices were all binary, but graphs indicated which elements are of biggest importance.
In the next step, the researchers have decided for a motive-oriented integration, since the aim was to enable the driver feel the status of his car with a new device. Many, highly associated to this overall theme, motives were identified in the DSM_motive, e.g. "reaching destination with energy resources", "feeling the energy flow in different driving situations" and "getting a feeling of electric energy consumption". The DMM_Motive-Need has shown that the needs primarily addressed are the needs for physical thriving, competence and pleasure-stimulation. The fulfilment of those needs was set as criterion for the success of the new device. Analysing the DMM_Function-Motive, functions which address the motives have been explored, such as "provide energy information", "control driving mode", "start/stop motor". The DMM_Function-Use case has provided additional information regarding the situations in which the functions and consequently the new device are likely to be used, like "driving ecologically" or "starting engine".
Having a selection of functions and clearly set criteria and use situations, the team proceeded to the creative part of creating new interface concepts. The integration concepts were communicated via UX stories and metaphors and have iteratively been implemented into sketches, experience prototypes and, finally, a demonstrator. The result was the "energy button" [Loehmann et al. 2014], a novel interface for controlling all functions related to the energy resources of the car. With the new control, 5 buttons/indicators were replaced by one element, making their use more intuitive. The device was evaluated by UX experts and industrial partners, and furthermore within user studies. The evaluation of needs fulfilment has been conducted as described by Koerber et al. [2013] and the results (needs for competence, stimulation and physical thriving were met) confirmed that it contributed to a positive UX.

5. Discussion

5.1 Opportunities and challenges

The suggested method increases understanding and forces collaboration within the UX design team in a holistic way. Data from many different sources are collected and experts of different backgrounds come together. The UX-related domains help designers consider the user's view and anticipate the emotional impact of technologies. The proposed approaches aim at arrangement of functions from user's perspective, instead of the conventional approaches of geometrical integration and 1:1 mapping of functions to interfaces. User-oriented function clusters lead to new integration concepts which are more likely to have a positive effect on overall experience with less perceived complexity. The different approaches help the UX team overcome fixations on existing solutions and to work bottom-

up (create new interface from a function cluster) or top-down (integrate new function in existing interface), depending on the project goal. Finally, the results are traceable (documented) and measurable (according to needs fulfilment).
Still challenges regarding the method applicability and outcomes need to be faced. Applying the method requires involvement of several stakeholders for a considerable amount of time: large amount of data needs to be collected from different sources, involving various company departments and potential customers. While applying the method, practitioners should make sure that the relations are not entered objectively, based on implicit knowledge, but based on data. When creating the integration concept, constraints have to be clear: are there, for instance components that must remain unchanged (e.g. due to safety issues)? Integrating too many functions into one component is the other extreme: designers must make sure that the new mapping/device/interface is understandable and intuitive to use.

5.2 Originality and limitations of the study

This study presents a matrix-based method to manage the complexity of UX and UXD processes. DSM and DMM approaches have not been considered in UXD so far, so the findings and suggestions of the authors would be interesting for the research community. The information used when applying the method already exists in the company; but knowledge is increased through better understanding of the relations among the elements by discussing and documenting results/data collected from various sources. Furthermore, novel ideas for new interaction elements are likely to occur. Another opportunity is using computations to visualize and calculate indirect relations.
A limitation of the current study is that the findings are based on lessons learned from one project within a specific frame, so the recommendations are mostly valid for similar applications. Still, the authors are confident that the application of the proposed method can contribute to management of UX-related elements, understanding of their effects and thus help creating better UX with complex products; the method was assessed by academics and practitioners involved in the project as beneficial even for the design of highly complex products and within complex organizational structures.

6. Conclusion and future work

Users need tools to accomplish complex tasks in dynamic use situations; but meanwhile want the experience of product interaction to be intuitive and enjoyable. Bringing order to complexity and making complex products understandable is the challenge which interdisciplinary UX teams face. To achieve this goal, applicable methods to explore experience-related factors and their effects are needed. A matrix-based method is proposed in this paper for handling technologies and motives and ordering/mapping functions from the users' perspective. Users' needs and motives, use cases, functions, markets and users are defined as relevant domains. Methods to derive the elements for each domain and approaches to explore important relations among them are presented. The suggested methodological proceeding is summarized in five steps, whose application is exemplarily highlighted in a case study. The method´s applicability and positive effect on UX were assessed within a research project, while high organizational effort was identified as major challenge in the application of the method.
Future work focuses on applying the method on further projects and product categories. Considering further approaches for function clustering, such as user- or market-based strategies are also exciting topics for future research. A further goal is to develop a guideline showing the most appropriate approach depending on project goal and product category. Further application also aims at adapting the approaches for a more simplified, realistic implementation.

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