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INTEGRATION OF THE WELL-BEING IN THE EARLY PHASES OF THE AUTOMOTIVE DESIGN PROCESS: FIRST APPROACH AND CONTRIBUTION OF PHYSIOLOGICAL MEASURES

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1. Introduction

People are increasingly concerned with their self-care and product designers offer a rising number of solutions in order to promote people's Well-being [Hearthmath 2010], [O.Zen Ubisoft 2015]. A growing number of companies are seeking a realignment of business goals away from profit and toward social good [Calvo and Peters 2014]. In the research field, a lot of researchers work at centering the design on the human in the design process, for example by integrating ergonomics [Sagot et al. 2003]. More specifically the role of products in human flourishing is emerging [Kamp and Desmet 2014]. Indeed some researchers are interested in Well-being integration in products -and services design. Hence some frameworks and theories are emerging as the positive technologies [Riva et al. 2012], the positive design [Desmet and Pohlmeyer 2013], the positive computing approaches [Calvo and Peters 2014]. In the same way, companies in general and especially those in the automotive industry, are for many years facing increased competition, which drives them to constantly renew their products and to offer increasingly competitive costs [Brissaud and Garro 1998], [Bennett 2008]. Because of strict performance requirements in terms of quality - costs - time and also because of the rise of global competition, cars manufacturers are constantly able to offer innovations while maintaining their brand identity to remain major players in the market [Kapferer 2002], [Snelders et al. 2011]. In this context, manufacturers are required to frequently offer new vehicles integrating new features and offering new services to the customer [Cagan and Vogel 2002]. In this way, a new research issue about the Well-being has been highlighted, among others, by the French car manufacturer Renault. This strategy is part of a wish to promote the Well-being of the driver. Thus researches are needed to gather knowledge about the integration of Well-being in the automotive design process in order to help manufacturers. More precisely, in the long term it should enable car designers to implement new functions promoting the driver's Well-being.

2. Research issues

In the automotive industry it is essential to integrate the different kinds of design specifications directly from the pre- and early phases of design projects [Norbye 1984], [Sako 2003]. This problematic is already addressed in the literature with several researches proposing different approaches to integrate new core competences (relating for instance to mechanics, style, ergonomics, etc.) into the products design process. The first approach started to be considered in the 90's and consists in gathering multidisciplinary design process methods. For instance we can mention the models from Garrigou

[1992] and Roussel [1996], which are especially dealing with the integration of the ergonomics in the early phases of design process. We also could mention models taking into account a feedback about experiences such as the retroactive and cooperative model defined by our research team [Sagot 1999], [Gomes 1999], [Mahdjoub 2007]. The second approach relates to complex products design and contains the tools and methods designed for the engineers enabling the integration of knowledge and skills coming from different core competences. For example Hermann et al. [2006] defined a method enabling product end-of-life integration from the early phases of the engineering design process. Peng et al. [2012] defined a visualization system enabling the integration of maintainability from the first phases of the design process. Some others authors help human factors integration as well, such as comfort, acoustic, vibration filtration and emotion [Morioka and Griffin 2008], [Da Silva et al. 2012], [Mohanty and Fatima 2013], [Herbeth 2014] while others researches are focused on style specifications [Bluntzer et al. 2012]. All together, these methods are dedicated to improve the design process by integrating several kinds of requirements during its early phases. Another model called "Multi-Domains / Multi-Viewpoints" (MD-MV model) [Gomes and Sagot 2002] actually combines the design representation proposed by Solehnius [2002] in terms of domains (customer domain, designer domain, manufacturing domain) and the system representation proposed by Le Moigne [1977] suggesting that a system can be observed from at least three viewpoints (structural, functional and dynamic). More specifically this model represents the design process by a domains network (Process, Product, Project, etc.) and as each domain is considered as a system it could be observed according to the different viewpoints (Figure 1). This model enables a better knowledge mapping of each core competence usually involved in a product design process.

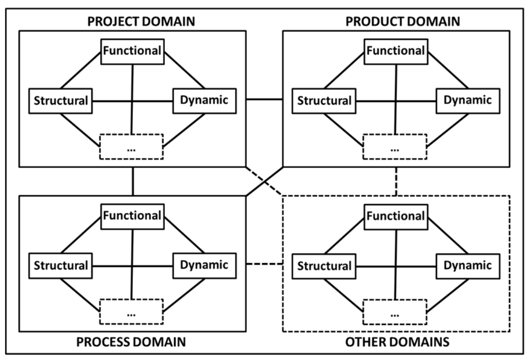

Figure 1. Multi-Domains / Multi-Viewpoints (MD-MV) model [Gomes and Sagot 2002]

Consequently, the present research work focuses on the integration of driver's Well-being into the early phases of the design process by relying on the MD-MV model. It is nevertheless important to point out that Well-being is in a certain way already taken into account into the design process. Indeed, some new vehicles are equipped with systems that are designed to improve drivers' Well-being, such as massages drivers' seat (product domain). However we consider the actual approach as opportunistic insofar as is revealed that the Well-being is taken into account during relatively advanced phases of the design process, more usually when solutions are chosen. Indeed each core competence (style, ergonomics, etc.) (paradigm (a) on the Figure 2) involved in the project domain can define the future on-board functionalities that are supposedly going to insure driver's Well-being by managing its own knowledge, systems, definitions, etc. We suggest to name these elements, aimed to promote the driver's Well-being, artifacts according to Simon [1969] and Rabardel [1995], in the sense that they are indeterminate things, not restricted to physical objects. In our opinion, the fact of adopting an opportunistic approach of Well-being integration implies that the design process is not optimized and proposed solutions may not be the most suitable for the driver's Well-being. Therefore we aim at transforming the present paradigm ((a) on the Figure 2) to the paradigm (b) where one Well-being artifact is defined in a human-centered approach and leans on Well-being research (including the theory and methods arising from this area). This new artifact should be then integrated by the existing core competences, thus helping the integration of the Well-being into the design process. In this way our research intends to define this Well-being artifact and to suggest how it could be integrated in the design process.

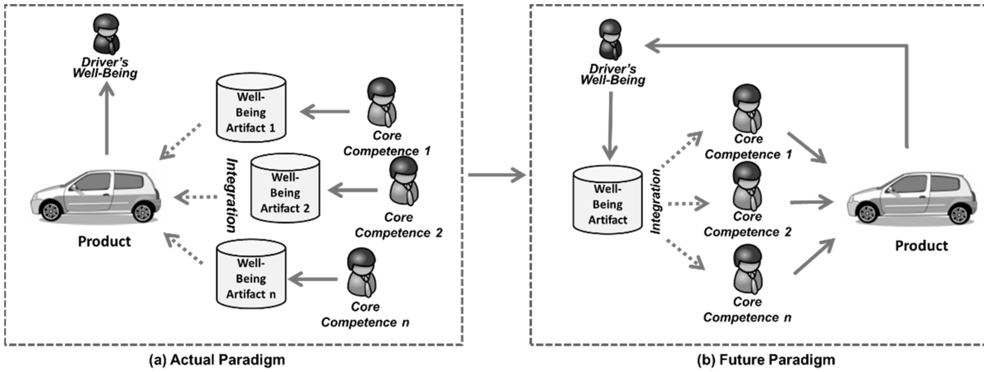

Figure 2. Actual and future paradigm of well-being integration in car design process

In this context, the present paper focuses on a first approach enabling definition of the Well-being artifact. As mentioned above, this artifact could contain any elements of different natures (methodology, knowledge, etc.). In order to well define those elements, we first set a definition of Well-being based on a literature review. This definition will be the cornerstone of the Well-being artifact. More precisely, since the literature focusing on the design for Well-being points out the necessity to consciously and systematically consider Well-being measures into the design and evaluation of technology [Calvo and Peters 2014], [Kamp and Desmet 2014], we focused our first experiment on the possibility to use physiological measures in order to quantify the driver's Well-being.

3. Well-being artifact

3.1 Definition of well-being

First of all, it is necessary to define as clearly as possible what Well-being means. Well-being concept has a long history in philosophy. Aristippus taught that the highest human's ambition was to experience as much pleasure as possible, which defines Hedonism. Therefore Well-being was back then considered as equivalent to the amount of hedonic experiences someone could get. Several centuries later, Kahneman et al. [1999] extended this hedonic perspective limited to sensual pleasures to all the pleasant experiences (i.e. positive emotions) and defined the subjective Well-being approach. Although subjective Well-being broaden the original hedonic concept, this emotionally-based viewpoint neglects some longer-lasting characteristics. Indeed, even though it is true that positive emotions are part of a happy life, they may not be a complete answer to lasting Well-being [Calvo and Peters 2014]. In order to take into account more than just positive emotions, the concept of Eudaimonic psychology was introduced. This concept introduces new characteristics such as engagement, meaning, human potential, etc. Therefore many current researchers include both Hedonic and Eudaimonic viewpoints in their Well-being Theories, such as the PERMA model [Seligman 2012] identifying five Well-being factors: positive emotions, engagement, relationships, meaning and achievement.

3.2 Well-being evaluation

As mentioned above, more and more researchers are interested in Well-being integration in products, technologies and services design. Among them, several researches pointed out the importance to define multidimensional measures and validated methodologies in order to collect data and evaluate Well-being impact of a new product [Desmet and Pohlmeyer 2013], [Calvo and Peters 2014]. A lot of subjective scales exist to assess the different Well-being factors, which could be relevant in the context of products design. But the problem with such methods is that they require to assess Well-being other time (for instance during a user test), so their use can become intrusive insofar as the user test has to be frequently interrupted. More over users' responses may not correspond to their actual experience [Marshall and Rossman 1999]. In order to overtake this limit, others approaches seems promising. Indeed Kahneman [1999] suggested that some information (especially related to the hedonic values) might be derived from non-invasive sources such as physiological signals. Nowadays this is one of the

goal of affective computing, producing a lot of research on different automated affect-detection techniques [Picard 1997].
In an automotive driving context, a lot of studies have used physiological parameters to measure objectively some states related to the driver's Well-being. In this way, Jansen et al. [2013] measured heart rate to determine specific emotion (e.g. anger). Others have quantified driver's stress level by measuring several physiological parameters such as the heart rate variability and electrodermal activity [Healey 2000], [Sena et al. 2014]. Tischler et al. [2007] studied driving pleasure by measuring physiological parameters such as skin temperature. A study included in a SAE report [2000-05-0329] focused on acoustic comfort measure by using several physiological measures including skin conductance. Even though those physiological measures are known to efficiently highlight several drivers states (such as stress, anger, etc.), no study considering the Well-being in a holistic way could be found. We thus propose an exploratory study in which a more holistic approach of the Well-being is at stake.

3.3 Experiment

Towards this end, we designed a first experiment, exploring the contribution of some physiological parameters for driver's Well-being evaluation. Based on a literature review about user experience evaluation with physiological data in an automotive context, we selected five physiological parameters: heart rate, breathing rate, skin conductance level, skin temperature on the head and skin temperature on the finger. We proposed different scenarios on a car driving simulator in order to induce different Well-being levels during which continuous physiological measures were carried out during: a Rest Period (RP), a Non-Degraded Well-being driving session (NDWB) and a Degraded Well-Being driving session (DWB). As described below we also used questionnaire in order to understand which states were exactly induced by the scenarios. The goals of this experiment were (a) to verify whether we actually induced different Well-being levels between each conditions, (b) to determine the evolution of the physiological profile according to the Well-being level and (c) to determine which physiological parameters are the most relevant to study Well-being. Our working assumptions were (a) that the level of Well-being would be higher during the RP than during the NDWB situation and higher during the NDWB situation than during the DWB situation, (b) that the physiological means would be higher during the DWB situation than during the NDWB situation and higher during the NDWB situation than during the RP and (c) heart rate and skin conductance would be more suitable to quantify the Well-being level, according to existing studies focused on psychological states related to Well-being [Helander 1978], [Healey 2010].

3.3.1 Participants

Seven volunteers (among which five women and two men) were recruited. They were all students from the Ergonomics, Design and Mechanical Engineering Department from the University of Technology of Belfort-Montbéliard in France. The average age was 21.7 (±1.4 years). All participants had their driving license for at least three years.

3.3.2 Materials

- Driving Simulator: a driving simulator composed of a panoramic screen was used to simulate the different driving conditions inducing different Well-being levels. It is composed of a panoramic screen (angle: 190 degrees; diameter: 6 meters; height: 2.5 meters).
- Electrocardiogram: we used the Vista Holter system in order to get the heart rate of each participant.
- Skin conductivity sensor: we used the Varioport system in order to measure the skin conductance level of each participant. According to the literature, electrodes should be put on the middle phalanges of the non-dominant index and middle finger [Fowles et al. 1981]. Nevertheless in a driving context some studies recommend to position the electrodes on the distal phalanges in order to avoid mismeasurement due to steering wheel handling [Petit-Boulanger 2011]. We choose this configuration for the experiment. Moreover in order to minimize artifacts due to the gear lever, we put the electrodes on the left hand by default.

- Breathing sensor: in order to get the breathing rate of each participant we designed a breathing sensor composed of a flex sensor (Flex sensor 2.2”) fixed on a belt, sending data to an Arduino Uno microcontroller board. Then the data were sent to the Computer in a Visual Studio application. The signal was filtered in post-analysis with Scilab software [Scilab Enterprises 2012]. We validated this sensor during a couple of tests (in laboratory and in road).

3.3.3 Procedure

Before the experiment, each participant first signed a consent form, and then was equipped with the physiological sensors. All of them filled out a background questionnaire, which was used to gather information on their driving habits, driving simulator experience, driving sickness sensitivity and personal information such as age. Then, each participant had a training period to get accustomed to the driving simulator.

During the experiment and as mentioned above, three situations were played out in a balanced order for each participant: the Rest Period (RP), the Non-Degraded Well-Being driving session (NDWB) and the Degraded Well-Being driving session (DWB). During the RP participants were invited to rest for a five minutes period in the vehicle. For the non-degraded Well-being driving session, participants drove on a quiet and harmless country road during approximately ten minutes. For the degraded Well-being driving session, they drove in a fairly crowded city center during approximately ten minutes with aggressive road users simulated by playing specific behavior such as tailgating, speeding, failure to yield the right of way, etc. This scenario was designed based on those used to induce stress or negative affects [Healey 2000], [Jansen et al. 2013], [Sena et al. 2014]. During all the experiment physiological data were continuously recorded and the primary experimenter interviewed the participants with questionnaires (see below) after each condition during approximately ten minutes.

3.3.4 Well-being questionnaires

We used a number of measures reflecting various aspects of Well-being. It was necessary to use French version of the questionnaires due to the native language of the participants.

- General Well-being scale. This scale was used in order to get a global Well-being score for each condition. We used a fifty points CPS (Category Partitioning Scale). This kind of scale was shown to be relevant (in term of validity and reliability) to study states like comfort [Shen and Parsons 1997]. More precisely, the scale was arranged vertically from 0, equal to “absence of Well-being”, to 50 equal to "very high Well-being". More precisely, there are five categories, each category being divided into 10 scale points: very slight, slight, medium, high, very high.
- Subjective Well-being. We first assessed the affective tone by using 20-items Positive and Negative Affect Schedule [PANAS], [Watson et al. 1988], assessing the affective arousal. We used a French version of this scale [Bouffard et al. 1997]. Then we assessed more specifically the emotional state by assessing both the valence (hedonic tone) and arousal (emotional intensity) dimensions by using the Pleasure Arousal Dominance [PAD], [Mehrabian and Russell 1974] scale. We used a French version of this scale [Ferrandi et al. 2002].
- Eudaimonic Well-being. For this first experiment we decided to use the flow factor, also known as optimal experience and described by Csikszentmihalyi [1990] and related to the engagement, as defines by Seligman [2012]. We used the Flow4D16 Scale designed by Heutte and Fenouillet [2010] evaluating the subjective feeling related to the flow state.

Theses questionnaires were used to confirm the assumption (a) that we actually induced different Well-being levels between each conditions. More specifically, by interviewing about specific states related to the Well-being, it should also enabled a better understanding of what was exactly induced by the different scenarios.

3.3.5 Results

Given our small sample size (N=7), a non-parametric statistical analysis was performed using the Friedman test which is the non-parametric alternative to the one-way ANOVA with repeated measures.

This test was performed on the physiological measures whose Means and Standard-Deviations are reported in Table 1. Significant effects were further investigated using Wilcoxon signed-rank test.

Table 1. Means and standard deviations for physiological parameters according to driving situations

	Rest Period	Non-Degraded Well-being situation	Degraded Well-being situation
Heart rate (beats/min)	70.1 (3.4)	74.9 (5.3)	76.3 (8.2)
Breathing rate (cycle/min)	13.9 (1.3)	19.8 (5.0)	19.9 (2.8)
Skin conductance level (μS)	8.4 (2.2)	8.7 (2.7)	9.4 (2.6)
Head skin temperature (°C)	34.1 (0.7)	34.1 (0.6)	34.2 (0.7)
Finger skin temperature (°C)	27.4 (5.8)	25.3 (4.6)	26.1 (4.5)

First the analysis showed that heart rate was affected by driving conditions, $\chi^2(2) = 9.3$, $p < .01$. Pairwise comparisons showed that the participant's heart rate was higher during both the NDWB and the DWB situations than during the Rest Period, $W = 21$, $p < .05$. Non significant differences were observed between the NDWB and the DWB situations, $W = 15.5$, $p > .1$. The analysis showed an effect of the conditions on the skin conductance level, $\chi^2(2) = 8.4$, $p < .05$ (Figure 3). Pairwise comparisons showed that there was no significant differences between the RP and the NDWB situation, $W = 10$, $p > .1$. The analysis showed that the skin conductance level was higher during the DWB situation than during the RP, $W = 21$, $p < .05$ and slightly higher during the DWB situation than during the NDWB situation, $W = 15$, $p = 0.059$.

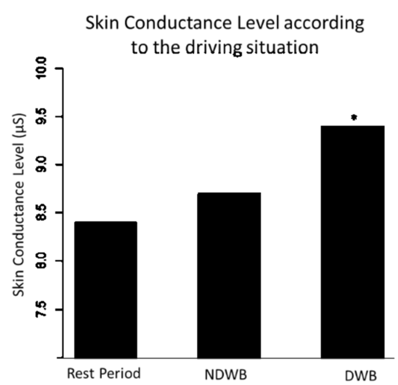

Figure 3. Skin conductance level according to the driving situation

Concerning the skin temperature on the head and on the finger, no significant differences were observed between the conditions, $\chi^2(2) = 4.6$, $p > .1$, $\chi^2(2) = 3.0$, $p > .1$. Although raw data about breathing rate seems interesting, acquisition issues for several participants did not enable us to perform statistical analysis.

The same non-parametric statistical analysis was carried out on the Well-being measures, after calculating means for each participant and condition (Table 2). First, the analysis showed that General Well-being level was affected by driving conditions, $\chi^2(2) = 10.57$, $p < .05$. Pairwise comparisons showed that the participant's General Well-being level was actually higher during the NDWB situation than during the DWB situation, $W = 28$, $p < .05$. Non significant differences were observed between the RP and the NDWB, $W = 8.5$, $p > .1$. All together, this showed that DWB leads to a decrease in Well-being as opposed to RP and NDWB.

The emotional valence was not significantly affected by driving conditions, whereas the analysis showed an effect of these conditions on the emotional arousal, $\chi^2(2) = 13.56$, $p < .01$. The pairwise comparisons showed that the participant's emotional arousal was higher during the NDWB situation than during the RP, $W = 28$, $p < .05$, and higher during the DWB situation than during the NDWB situation, $W = 21$, p

< .05. Regarding the affective state, the analysis showed an effect on the negative affects, $\chi^2(2) = 7.64$, $p < .05$. Nevertheless pairwise comparisons showed only significant differences between the RP and the DWB situation, showing that DWB leads to an increase in negative affects as opposed to RP and NDWB. Then, the analysis showed a slight effect of the situations on the positive affects, $\chi^2(2) = 5.85$, $p = .054$. Surprisingly, pairwise comparisons showed that the positive affects levels were higher during the NDWB and DWB situations than during the RP, respectively $W = 27$, $W = 26$, $p < .05$. Concerning the Eudaimonic Well-being, assessed in this study by the flow level, no significant differences were observed between the conditions, $\chi^2(2) = 3.43$, $p > .10$.

Table 2. Means and standard deviations for general well-being and specific states according to driving situations

	Rest Period	Non-Degraded Well-being situation	Degraded Well-being situation
General Well-being	37 (5.7)	34.3 (10.8)	20.4 (11.0)
Emotional valence	19.7 (5.0)	19.9 (3.5)	15.9 (4.1)
Emotional arousal	9.4 (3.1)	16.4 (3.5)	19.4 (2.5)
Positive affects	19.9 (6.0)	33.1 (6.4)	33.4 (7.5)
Negative affects	11.6 (1.7)	14.4 (6.6)	18.1 (5.2)
Flow	56.3 (7.3)	56.4 (6.7)	51.0 (9.2)

3.3.6 Discussion

Skin conductance level and heart rate seems to be promising to measure Well-being as it responded differently to the different driving condition. Nevertheless these parameters seem to have different behaviours. Indeed, while the significant variation of the heart rate occurs between the RP and the two "active" driving situations (NDWB and DWB situations), the increase of the skin conductance level occurs mainly during the DWB situation, wherein a more important mental activity is induced. Then these results would be consistent with the Helander [1978] study, analysing the physiological responses to the traffic environment and concluding that the electrodermal responses were induced by the mental effort of the driving task rather than the physical effort necessary to maneuver the vehicle. In our experiment, since the RP is defined by an absence of physical activity, it is possible that heart rate variations were partly due to the physical activity of the participants.

As opposed to skin conductance level and heart rate, skin temperatures was not responsive to the different Well-being scenarios. Indeed analysis showed we succeeded in inducing at least two different Well-being levels (NDWB and DWB situations), however none skin temperatures variation were observed.

All together, the analysis showed that skin conductance level and heart rate were more suitable to quantify the driver's Well-being, validating the working assumption (c) that heart rate and skin conductance level are more suitable to evaluate the Well-being of the driver. Moreover we observe a general tendency in heart rate and skin conductance level to increase according to Well-being degradation, validating assumption (b) that the physiological means to evaluate Well-being would be higher during the DWB situation than during the NDWB situation and higher during the NDWB situation than during the RP. Nevertheless this conclusion should be done with caution. Indeed, although we did the assumption that Well-being level would be the greater during the Rest Period, analysis actually showed non significant differences between the RP and the NDWB situation. Therefore assumption (a) that the level of Well-being would be higher during the RP than during the NDWB situation and higher during the NDWB situation than during the DWB situation is not completely confirmed. More surprisingly some participants felt even more Well-being during the NDWB situation than during the RP. Questions about specific states related to the Well-being help us to understand this result. Indeed we observed that the level of positives affects was significantly lower during the RP than during the others situation. As the PANAS scale assessing this Well-being component refers to - among others things - the interest, the excitement, the enthusiasm, we can conclude that the RP was surely too boring for the participants. This assumption seems to be confirmed by the emotional arousal analysis showing a very low level during the RP compared to the NDWB and the DWB situations. By the way the emotional arousal results explain why the Well-being level was actually the lowest during the DBW situation as well. Finally it seems that the RP represented not enough interest for participants while the DWB situation was too demanding. The fact that some physiological parameters were however higher during the DWB than during the RP shows that it will be surely difficult to measure accurately the positive affects tone with physiological measures.

Then, while literature shows the importance of eudaimonic component in the Well-being (measured in our experiment through flow dimension questionnaire), present results showed we did not induce different Well-being level in a holistic way. As the emotional arousal results suggest, we rather induced different states of stress like the study carried out by Healey [2000]. In other words the Well-being states playing during this study were too restrictive. This study should thus be enlarged by defining scenarios inducing more Well-being dimensions and not only the Hedonic component. It will be necessary in order to be as relevant as possible in the definition of this evaluation method, which will be one of the main part of the future Well-being artifact. Then, as the inter-subject variabilities in terms of physiological and subjective measures show (illustrated by the standard deviations in the Table 1 and 2), such a Well-being evaluation during the design process should be used as relative rather than absolute assessment. It is also important to notice that although a driving simulator allows to control some parameters proved to be uncertain in on-road context, such as room temperature, humidity, etc., it could represents some limitations as it does not exactly replicate on-road driving behavior [Mullen et al. 2011]. And finally, the small sample size (7 participants) does not allow us to draw definitive conclusions.

4. Conclusion

In the present article, we propose to integrate the driver's Well-being into the early phases of design process by relying on the MD-MV model. More specifically it consists on defining how driver's Well-being impacts each domains of the design process (e.g. project domain) and according different viewpoints (e.g. the functional viewpoint, corresponding in the project domain to the function of each core competence). This approach led us to define what we called a Well-being artifact, bringing together knowledge, methods, etc. that we could propose in the future to the car designer in order to integrate the Well-being. We have seen how important are the setting of a scientifically based definition and evaluation methods for a systematic consideration of Well-being in the design process. Therefore we suggest to use a definition of Well-being incorporating both the Hedonic and the Eudaimonic tone as it is defined in the literature and working on evaluation means of Well-being. Such an evaluation could be used in the future to assess the Well-being impact of a new system during the design process. In this way we proposed an experiment in order to study the contribution of physiological measures to assess the driver's Well-being level. We observe that some physiological parameters such as heart rate and skin conductance would be relevant to carry out such evaluation. Moreover this exploratory study helps us to better understand the link between subjective states related to driver's Well-being and physiological state. However some limitations of the present experiment lead to the necessity to carry out new experimental studies in order to confirm these assumptions or draw other conclusions. The limitations could have also some implications for a future integration into the design process like the necessity to carry out this kind of evaluation in on-road context or the necessity to realize relative rather than absolute assessment.

Although we focus in this paper on the definition and on the evaluation means (definition space and evaluation space in Figure 4), the definition of Well-being artifact should also concerns the design space, for example by implementing design strategies for Well-being. As these design strategies would be transitional objects enabling the designer to propose solutions responding to the different Well-being Factors, we propose to call it Vectors. More interestingly the assessment methods we presented could be then implemented to validate for example these design Vectors. Finally it will consist in integrating this artifact into the design process. For example, the different tools, knowledge, methods, etc. constituting the future Well-being artifact could be implemented into the existing core competences, impacting therefore the functional viewpoint of the project domain of the MD-MV model. Indeed, existing core competences would have therefore new functions, tools or working methodologies.

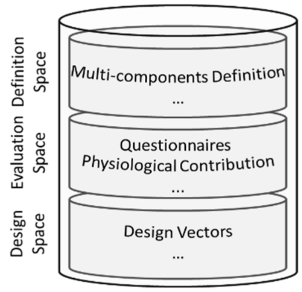

Figure 4. Current artifact components

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