USING BCIs (BRAIN COMPUTER INTERFACES) TO EVALUATE EMOTIONAL PERCEPTION OF PASSENGER CABIN DESIGN IN VIRTUAL ENVIRONMENTS

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Abstract

Cabin interiors design can be considered one of the key enablers to face the societal challenges of future air transport.

The cabin is the interface between the aircraft and the passenger and it strongly impacts on the user's experience. The quality of the travelling depends on the quality of the cabin. It could be measured through several and different dimensions, such as passenger's efficiency during and after the flight and the level of comfort that he/she experiences. Therefore, reading or working while flying or feeling restored when leaving the cabin should be the key performance indicators of a comfortable cabin.

In this paper we propose an innovative design tool, that is an objective method to measure the affective impact that interior design provokes to passengers, with particular regards to seat design. Such method is based on the use of large virtual environments, coupled with BCIs (Brain Computer Interfaces). We propose a novel and original framework to correlate the BCIs affective scales to a set of comfort indicators. Experimental results are presented and discussed.

1 General Introduction

The enhancement of passenger comfort and ergonomics in aircraft cabins is a major objective of future aircrafts. Innovative concepts are being proposed in order to provide design solutions that meet companies' needs to reduce costs and satisfy user's requirements. Besides the air-conditioning optimization and the reduction of noise and the vibrations, a major component of the overall comfort of passengers is a positive perception of the spaces in the cabin. The perception of larger or narrow volumes available for the passengers may depend on the seats design and cabin layout.

According to the aesthetic economical model proposed by [1], comfort is perceived as being in an interesting, advanced and beautiful environment, available for a reasonable price. Nevertheless, in order to gain the maximum seats/fuselage ratio, mostly in regional flights, the distance between rows (pitch) and the number of seats per row are not optimised. This can cause discomfort to passengers, not only in terms of effective volume for movements, but also for the frustration of being immersed in a dense environment. In the evaluation of alternative design solutions in the earliest design stages, the main issues are the availability of large mock-ups and of methods to capture user's perception in terms of emotional feelings inspired by different cabin layouts.

Virtual Reality technologies allow performing the design review of large mock ups in immersive or semi immersive environments [2]. Affective evaluations of users' impressions through virtual prototypes have also been described. Nevertheless, the evaluation of alternative configurations is based on subjective rankings that the participants perform by filling questionnaires [3].

In this paper we propose an innovative and user centred method to support the early design process of the cabin. A BCI system is used to evaluate the emotional perception of cabin layouts virtually prototyped on a large immersive display (CAVE - Cave Automatic Virtual Environment).

Experimental results are presented and discussed with reference to a case study on the layout of the passenger cabin of a short/medium haul aircraft. This study intends to contribute to a major and a better involvement of the final user in the design of aircraft interiors. To this aim we propose a system and an objective evaluation method that can fill the gap between the passengers and the designers.

2 Cabin & Seat Design

The design of the cabin and of its layout determines the aircraft's payload, and, in commercial aviation, it consists of the passengers and their baggage.

Thus, the layout of passenger cabin is the first step to estimate the length and diameter of the fuselage. If N_P is the desired number of passengers, designers have to find the optimum ratio of the length to the diameter, which will meet aircraft's mission parameters.

The diameter determines the number of seats abreast N_a, while the length identifies the number of rows N_r. The number of passengers results in:

$$N_P = N_a N_r;$$

The width of the fuselage in the cabin region b_f is proportional to the total width of seats and aisles.

$$b_f \sim aN_a + a'N_{a\prime}$$

where a is the seat width, a is the aisle width, and $N_{a\prime}$ is the number of aisles [4].

Therefore, such parameters have to be identified and considered in seat design in order to gain the desired layout. Another important parameter is the seat pitch. It provides an indication of legroom, referring to the space between a point on one seat and the same point on the seat in front of it.

Such seating dimensions have to be optimised in order to meet regulation requirements, maximum payload and adequate comfort of passengers [5]. Typical seating dimensions for the first class and for the economy class are shown in Table1 [6].

Table 1 Typical Seating Dimensions

Description	First class	Economy
Seat width *a*	17-22 in	17-18 in
Armrest width	2.75 in	2.0 in
Aisle width *a'*	18-20 in	16-18 in
Pitch *P*	37-46 in	30-38 in
Seat height	41-44 in	36-41 in

Authorities usually set standards, specifically for the pitch, in order to assure safe evacuation times based on mean anthropometric databases. Thus, a minimum pitch value is set. The comfort of passengers is then up to the airliners.

The two most popular low cost regional airliners in Europe declare that the pitch on their aircrafts is 29"/30" and the seat width is 17.5"/17".

Assuming that safety issues are satisfied with such values, it is evident that passengers' comfort decreases significantly.

Therefore, one of the greatest challenges is to find the configuration of seats that maximizes the space and improves passenger's comfort. As such, many designers and manufacturers have developed seating design concepts to solve common problems such as posture or general comfort of passengers [7], [8].

Travelling with some airliners, passengers can book two seats for one single person. The second seat is named comfort seat. Other aspects that impact on comfort of passengers are due to the human factors issues, such as the claustrophobic sensation due to the being immersed in a closed, crowded and dense environment. This paper focuses on such specific component of the comfort. It aims at investigating whether an unconventional design of seats, constrained to the aforementioned dimensions, impacts on the perception of the free space available to the passenger and how we can measure an improvement in passenger comfort in a virtual environment and based on objective evaluation parameters.

3 Virtual Prototyping on Large Displays

More than 20 years have passed since the CAVE (Cave Automatic Virtual Environment) concept was initially described by Cruz-Neira [10]. A number of configurations and applications have been proposed since then. The CAVE complexity depends on the number and on the layout of the multiple screens that aim at an immersive replica of real environments in virtual scenarios. Industrial Design, Architecture, Cultural Heritage and Medicine are the main application fields that have been explored within virtual worlds [11] [12] [13] [14] [15] [16]. Therefore, multi-projection displays are still considered to be an excellent way to reach a high level of presence [17]. Such systems allow examining perception questions and drawing conclusions about the users behaviour in the virtual environments.

For this reason these systems are particularly suitable to bring the early design stage of the aircraft cabin layout at a high level of fidelity (Fig.1). Models can be displayed at a large scale and with the depth illusion compared to the paper or desktop prototyping based design reviews.

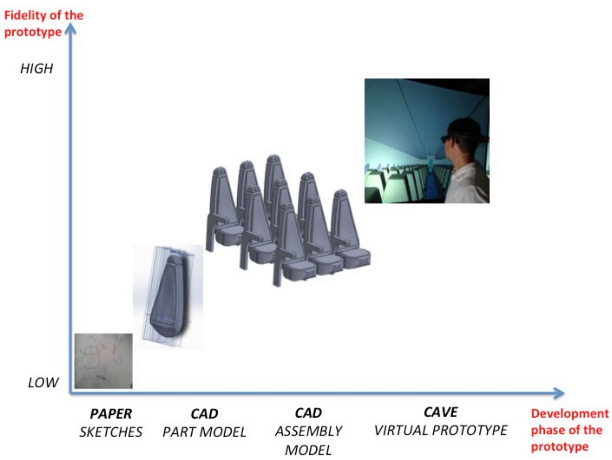

Figure 1 Prototyping phases in early seat design

The experimental phase of the present work took place in the RVE (*Reconfigurable Virtual Environment)* at the Virtual Reality Lab of the University of Bologna. The RVE is a modular environment with 3 rear-projected screens each mounted on a wheeled cubic structure. Each screen covers a 2.5 m x 1.5 m area. Therefore, the total projection area is 7.5x1.5 m^2. Multi-display functionalities are activated through a NVIDIA® 3D Vision® Pro architecture while stereoscopy is implemented by active shutter glasses compatible with the NVIDIA systems.

Three different design alternatives for the seat design are proposed.

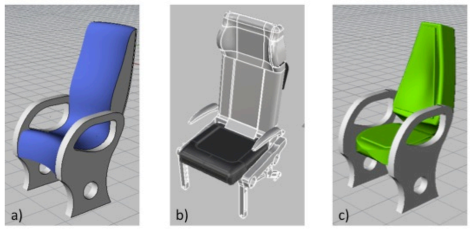

Figure 2 CAD models of the seat concepts: a) one shell b) innovative materials c) egg-shell

The three concepts derive from three different design objectives and are shown in Fig 2. The first one aims at integrating the seat in one shell in order to have a simple and linear shape easy to maintain and with an industrial design flavour. The second one is a traditional design in the shape, but the optimization regards the innovative materials proposed to increase the safety and load performances. The last one has been named the "egg chair", due to the egg-inspired shape. The top of the chair has been considerably narrowed. This choice has been done in order to apply the Gestalt psychology approach. Based on this theory, the seat designers assume that the passengers perceive the environment as a whole, and the reduction in the volume of the seat back should impact on the visual perception of the fuselage and the seats elements.

The three seat concepts have been then adapted to the same regional aircraft cabin model in order to build up three layouts with common features. With the aim of concentrating the evaluation on the seat design alternatives and on the impact that a single seat design has on the whole cabin, the same cabin has been arranged with the same layout (six seats abreast and one single aisle) and the same pitch has been maintained (Fig. 3).

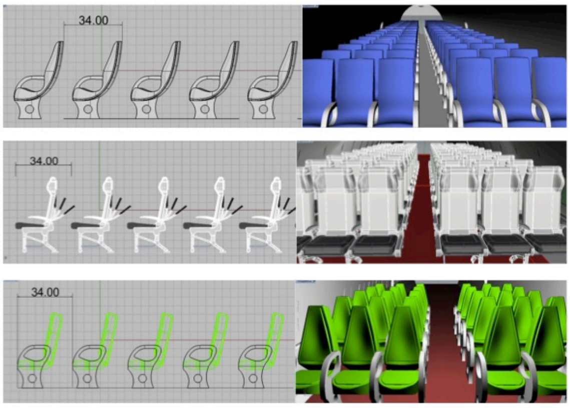

Figure 3 CAD models of the cabin lay outs

4 Emotional Design and BCIs

Besides weight and structural performances designers should consider also the comfort and attractiveness in terms of seat design, placement, storage space and safety during emergencies. Human factors engineering and ergonomics are the disciplines that help in the assessment of a specific seat design from the passenger's point of view.

In this framework we aim at evaluating the emotional response of passenger to different design alternatives. The importance of this aspect has been highlighted in the past studies and has been interpreted in different ways. It has been recognized that, usually, human factors have just tended to concentrate on making functional product benefit while feelings associated with using pleasurable or unpleasant products, such as pride/excitement or anxiety/frustration are to be considered in order to maximize the user's experience of a product [18]. It is evident that these factors are mainly considered for marketing purpose in mass product design [19].

In order to understand if a product induces positive or negative emotional effects we should be able to recognize and measure the user's experience. It has been demonstrated that a mental pattern exists for affective response to design [21]. Affect is defined more as "a short term, discrete, conscious subjective feeling" [22].

Desmet and Hekkert introduce a general framework for product experience that applies to all affective responses that can be experienced in human-product interaction [23].

These methods can be very appropriate to evaluate some important psychological factors for the aircraft passengers.

In order to capture the user's emotion in this work an Emotiv© neuro-headset has been used. The use of the unconscious information in addition to conscious commands is being considered as a very promising application of non-invasive BCIs devices. The Emotiv© neuro-headset is capable of monitoring the emotional states in real-time and, thus, can be used to monitor the user's state of mind in real life immersive situations. In product design evaluation, this can be a precious source of information providing a new type of feedback from users. The traditional method in evaluating product usability or an aesthetic design is performed by testing products and collecting subjective ratings; such methods can be influenced by the questions in the form that the users are asked to fill. Moreover, some features, like the "comfort" or the "discomfort" level, can be difficult to be identified with these tools.

With the help of the non-invasive neuro-headset, emotions of the user being felt unconsciously, hence without the influence of any external sources, can be captured and related to the corresponding environment he/she is being immersed in. The neuro-headset captures the electrical signals emitted by the neurons, it then classifies them depending on their frequency and amplitude into the corresponding type of emotion. The emotions that this evaluation method is referring to are the engagement, frustration and excitement levels. The related emotions corresponding to the excitement are nervousness, agitation and titillation; whilst the related emotions to what this study is referring to, as engagement is alertness, stimulation and interest [24].

5 Experiment setup

The focus of this study is to evaluate the user's emotions with respect to the design of the cabin projected on the RVE of the University of

Bologna. Based on OCC model of emotions [25], the emotions are categorized into three classes as a relation to events, agents or objects; moreover according to that model, getting the agent's emotional reaction to an event depends on the goals and desires of the person. Therefore, along with the unconscious data measured from the neuro-headset, a questionnaire divided in three parts is filled before and during the experiment.

Twenty-one students, aged 19-30 with the majority aged around 21 years, participated to the experiment. Prior to presenting the layouts, the fourteen sensors headset is placed properly on the passenger's head, allowing for the signals to stabilize and let the passenger tester get accustomed to the laboratory environment in order to avoid any influence on the emotions reflected since humans are affected by emotions, even if they are not showing that particular emotion [27].

The first approach towards the "virtual passenger" has been to inquire about his/her intention in spending the flight, and his visual expectations when entering the aircraft (Fig.4).

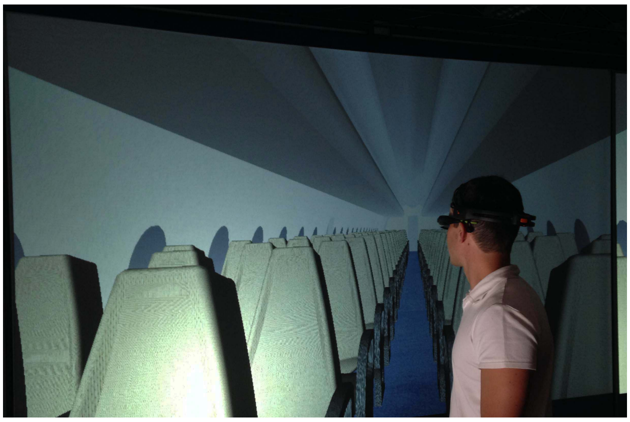

Figure 4 Snapshot of the Experimental Phase

Afterwards, moving paths inside the layouts were presented to the virtual passenger in order to simulate the entrance and walk through in the cabin. After that each display questions were asked regarding the cabin already shown. The questions were focused on three key items: the visual comfort (level of confidence felt with respect to the environment), the like (or dislike) and the "fly again" factor. (See Fig. 5).

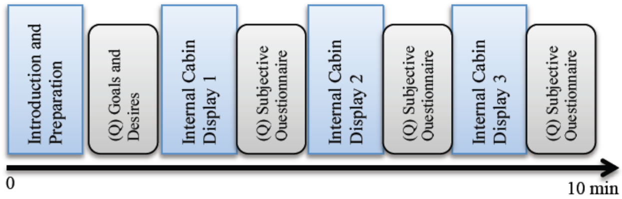

Figure 5 Study Procedure of the Experimental Phase

The definition of comfort is ambiguous since what is usually perceived is the discomfort level; moreover the human perception to comfort is subjective and depends on environmental conditions (such as temperature, humidity, noise level, vibration and pollutants) and personal conditions (such as health, physiology and psychological attitude). Therefore, the estimation of comfort (or discomfort) can rely on the feelings felt during the presentation of each layout by referring to the level of Engagement, Frustration and Excitement measured unconsciously.

6 Results & Discussion

Capturing the brainwaves hence the emotions and identifying the different subjective answers regarding the design evaluation criteria, significant results were obtained for the three cabin layouts. The emotions were classified based on the corresponding measured amplitudes. A complete list of the results is presented in tables 2, 3 and 4: each rating criteria and its corresponding evaluation based on the questions asked are displayed in the first columns; next are presented the emotional data captured from the neuro-headset. For each of these latter the percentage of testers that assessed the corresponding evaluation criteria along with the obtained range of amplitude of the corresponding emotion are shown (minimum amplitude – maximum amplitude).

The high rating of comfort (Table 2) resulted in all the cases in a high feeling of engagement for all the raters with 88.9% of low excitement. On the frustration data, half of the raters (55.6%) for a high comfortable environment had a low level of frustration.

Expecting to have a low level of frustration in a high comfortable environment, the high level obtained (in 44.4% of the cases) could be due to the fact that in an airplane, a passenger is not able to have control on the environment, hence a feeling of frustration might arise even though he/she finds the cabin layout welcoming and visually comfortable.

A rating of medium comfort in the design, caused the totality of the passengers to be highly engaged showing a high interest in the environment; 81.5% of these category of raters had a low level of excitement showing a low nervousness level; while frustration was divided into two categories: 51.9% with a low level of frustration and 48.1% with a high level. Rating a cabin layout as having a medium comfort is balanced between two cases: the high and the low comfortable evaluation. A frustrated passenger rating the comfort as medium leveled reflects that the environment evaluated tends to fall in the low comfortable category, whilst the rating of the not-frustrated passenger suggests the cabin layout is rather highly comfortable.

A low comfort rating reflects also a high engagement and excitement feeling; in this rating evaluation, the frustration measured was in 65.2% of the cases high. Proving that a low comfortable environment reflects in stress and anger in the passenger.

Rating Criteria	Design Evaluation	Emotional Data					
		Engagement		Frustration		Excitement	
		Percentage of Testers (%)	Range of Amplitude	Percentage of Testers (%)	Range of Amplitude	Percentage of Testers (%)	Range of Amplitude
«Comfort»	High	100.0	0.548 - 0.774 or 1	55.6	0.327 - 0.535	88.9	0.146 - 0.598
	Medium	100.0	0.548 - 0.987	51.9	0.194 - 0.512	81.5	0.247 - 0.528
				48.1	0.576 - 0.979 *or 1*		
	Low	95.7	0.548 - 0.980	65.2	0.596 - 0.967	78.3	0.275 - 0.598

Table 2 Results of Emotional Data in Function of the "Comfort" Rating Evaluation

The frustration amplitude reflects the level of annoyance and could be used as a primary factor in the comfort assessment of an environment. Prior to checking the frustration response, the level of engagement of the user should be high reflecting that he/she has a high interest in the environment while on the other hand, the excitement level is supposed to be low representing a low level of nervousness.

Regarding the likeness assessment (Table 3), a high engagement in both cases (like or dislike rating, 100% and 87.5% respectively) was observed, along with low excitement levels (88.9% and 56.3% respectively). Disliking an environment resulted in a higher level of low amplitude excitement (minimum amplitude of 0.596) compared to the amplitude of that latter when liking the environment (minimum amplitude of 0.576).

The feeling that could be a major factor of emotional assessment is the frustration correlated to the excitement measurements: high amplitude of frustration indicates a dislike assessment. The level of dislike could be assessed based on the amplitude of excitement felt: the higher the excitement the more the passenger disliked the layout.

Rating Criteria	Design Evaluation	Emotional Data					
		Engagement		Frustration		Excitement	
		Percentage of Testers (%)	Range of Amplitude	Percentage of Testers (%)	Range of Amplitude	Percentage of Testers (%)	Range of Amplitude
«Likeness»	Like	100.0	0.548 - 0.987	50.0	0.194 - 0.500	88.9	0.247 - 0.528
				50.0	0.576 - 0.979 *or 1*		
	Dislike	87.5	0.551 - 0.892	75.0	0.596 - 0.967 *or 1*	56.3	0.346 - 0.553

Table 3 Results of Emotional Data in Function of the "Likeness" Rating Evaluation

The "Fly Again" factor (Table 4) resulted in a high engagement and frustration level. The difference between the two cases in that evaluation is the excitement level.

Rating Criteria	Design Evaluation	Emotional Data					
		Engagement		Frustration		Excitement	
		Percentage of Testers (%)	Range of Amplitude	Percentage of Testers (%)	Range of Amplitude	Percentage of Testers (%)	Range of Amplitude
"Fly Again" factor	Yes	85.7	0.551 - 0.987	54.3	0.572 - 0.926 *or 1*	88.6	0.247 - 0.534
	No	85.7	0.552 - 0.892	64.3	0.596 - 0.967	50.0	0.314 - 0.553
						50.0	0.596 - 0.967

Table 4 Results of Emotional Data in Function of the "Fly Again" Factor Rating Evaluation

Comparison between both conscious results (from the results regarding the questionnaire) and unconscious (from the emotions deduced from the brainwaves) resulted in the correlation summarised in table 5.

Table 5 Design Evaluation Criteria Correlated with Emotional Data

Rating Criteria	Design Evaluation	Emotional Data		
		Engagement	Frustration	Excitement
"Comfort"	High	High	Low	Low
	Medium	High	Low/High	Low
	Low	High	High	Low
"Likeness"	Like	High	Low/High	Low
	Dislike	High	High	Low
"Fly Again" factor	Yes	High	High	Low
	No	High	High	Low/High

Figure 6 depicts a plot of emotions measured with respect to the time in which a cabin layout was projected. The passenger assessed the environment as low comfortable, dislike and a negative "Fly Again" factor. Prior to assessing the emotions, the high engagement of the assessor reflects that he/she is alert and interested in the layout; hence the interpretation of his/her emotion can be reliable.

The frustration amplitude reveals the low comfortable effect the environment had. Comparing this feeling to the excitement level, the "dislike" assessment is presented in terms of the emotion felt. The high frustration along an increasing level of excitement reveals the "No Fly Again" factor.

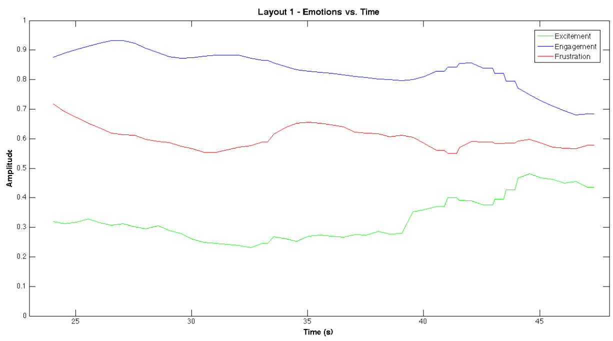

Figure 6 Emotion vs. Time

7 Conclusions

The results presented and discussed in this paper are the first steps towards the adoption of new tools for the design of user centred products and systems in aeronautics.

Traditionally, the design of aircrafts takes a considerably long time, compared to other industrial systems. Design teams in this field focus on technical issues even if the subsystems feature, such as the seats and the cabin architecture, strongly impact the affective response of passengers. With the growing number of passengers and the more intensive use of the air transportation even for regional flights, the market will have to focus on new needs, such as the well being and productive time of the flying people. The opportunity to quantify the affective impact by means of psycho- physiological measures is a challenging objective for future studies. According to the authors, two main aspects need to be analysed more deeply. The first one concerns the refinement of a robust correlation framework between the subjective and the psyco-physiological measures. Moreover, authors are planning to use the results of this paper to develop innovative design methods and procedures that take into account affective evaluations performed with BCIs with the aim of leading the design projects to affectively optimised solutions.

8 References

[1] Dumur E, Barnard Y and Boy G. Designing for comfort. *Human factors in design*, pp. 111-127, 2004.

[2] Choi S H and Cheung H H. "Virtual Prototyping for Rapid Product Development."

[3] Chulwoo K et al. Affective evaluation of user impressions using virtual product prototyping. *Human Factors and Ergonomics in Manufacturing & Service Industries,* 21.1, pp 1-13, 2011.

[4] Sforza P M. *Commercial Airplane Design Principles*, 1st edition, Elsevier, ISBN 0124199771, 2014.

[5] Quigley C et al. Anthropometric study to update minimum aircraft seating standards, 2001.

[6] http://www.seatguru.com

[7] Tan C et al. Sleeping posture analysis of economy class aircraft seat. *World Congress on Engineering*. 2009.

[8] Eden P, Cabin delivery, Airbus style, www.aircraftcabinmanagement.com, july 2013.

[9] Carter S. Case study: The application of TRIZ to economy class aircraft cabin design. *TRIZ-journal*, 2001-12, http://www.triz-journal.com.

[10] Cruz-Neira C, Sandin, DJ and DeFanti, T A. Virtual Reality: The Design and Implementation of the CAVE. *Proceedings of SIGGRAPH '93 Computer Graphics Conference, ACM SIGGRAPH*, pp. 135-142. August, 1993.

[11] Choi S H, and Cheung H H. A versatile virtual prototyping system for rapid product development. *Computers in Industry,* pp. 59.5, 477-488 2008.

[12] Abhishek S, Vance J M and Oliver J H. Virtual reality for assembly methods prototyping: a review. *Virtual reality,* 15.1, pp. 5-20, 2011.

[13] Tutt D and Chris H. "Journeys through the CAVE: The use of 3D immersive environments for client engagement practices in hospital design." 2013.

[14] Reich D and Dittrich E. Empirical Investigation of Transferring Cockpit Interactions from Virtual to Real-Life Environments. *Virtual, Augmented and Mixed Reality. Systems and Applications*. Springer Berlin Heidelberg, pp. 301-309, 2013.

[15] Carrozzino M et al. Interactive Visualization of Crowds for the Rescue of Cultural Heritage in Emergency Situations. *SCIRES-IT* 2.1, pp. 133-148, 2012.

[16] Runde C, Girbacia F and Butila E. Virtual and Augmented Environments for Concurrent Engineering: Concurrent Virtual Engineering, Concurrent Engineering Approaches for Sustainable Product Development in a Multi-Disciplinary Environment 2013, pp 849-860. doi: 10.1007/978-1-4471-4426-7_72.

[17] Majumder A and Sajadi B. Large Area Displays: The Changing Face of Visualization. *Computer*, vol. 46, no. 5, pp. 26-33, May, 2013, doi:10.1109/MC.2012.429.

[18] Jordan P W. Human factors for pleasure in product use. *Applied ergonomics,* 29.1, pp 25-33, 1998.

[19] Seva R R, Henry Been-Lirn D and Martin G H. The marketing implications of affective product design. *Applied Ergonomics,* 38.6, pp. 723-731, 2007.

[20] Esfahani E T and Sundararajan V. Using Brain–Computer Interfaces To Detect Human Satisfaction In Human–Robot Interaction. *Int. J. Human. Robot.* 08, 87, 2011, doi: 10.1142/S0219843611002356.

[21] Kun-An H and and Chen LL. Fundamental dimensions of affective responses to product shapes. *International Journal of Industrial Ergonomics* 36.6 pp. 553-564, 2006.

[22] Bentley T, Johnston L, von Baggo K. Evaluation Using Cued-recall Debrief to Elicit Information about a User's Affective Experiences. Proc. of CHISIG '05, *ACM International Conference Proceeding Series*, vol. 122, pp 1-10, 2005.

[23] Desmet P MA and Hekkert P. Framework of product experience. *International Journal of Design,* 1.1, pp. 57-66, 2007.

[24] Emotiv. Emotiv Software Development Kit - User Manual for Release 1.0.0.5. 2011.

[25] Ortony A, Clore G L and Collins A, (1988). *The Cognitive Structure of Emotions*. Cambridge University Press, 2003.

[26] Picard R W. Affective computing: challenges. *International Journal of Human-Computer Studies*.

[27] Bor R. Psychological factors in airline passenger and crew behaviour: a clinical overview. *Travel medicine and infectious disease,* 5.4, pp. 207-216, 2007.

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