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GLASS AND WINE: THE INDISSOLUBLE MARRIAGE

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ABSTRACT

The FBS model describes theoretically the design process of a product. Only few papers present real industrial case studies, which are generally finalized to illustrate theoretical concepts.
The aim of this paper is to show a methodology and its testing on the design of new tasting glasses, based both on the FBS model and on experimental analysis. This is an interesting theme in the food design area. Indeed a tasting glass is the interface used to convey wine characteristics to human senses (sight, taste and smell). The glass influence on the evolution of sensory perception of wine is not fully understood and rarely evaluated.
The analysis is composed of: (i) an experimental activity to understand the evolution of sensory profiles of a well-structured red wine maintained in different types of glasses through expert testers, (ii) the selection of one of the most important function carried on by the product, and therefore the study of the related behaviours, (iii) the identification of the correlation between the behaviours and the design parameters of the glass. Finally a method and tools to extract and measure the geometrical feature of the glass are presented.

Keywords: design methodology, new product development, design practice, functional modelling, functional analysis

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1 INTRODUCTION AND STATE OF THE ART

The FBS framework is one of the most popular representation of the design process. It is useful to develop computational design agents as aids to human designers (Gero et al., 2004). It is based on three main classes of variables: Functions (F) that take charge of the teleology of the product, what it is for; Behaviour variables (B) describe the attributes derived from the structure, i.e. what the product does; and the Structure (S) variables describe the components, what the object is (Gero et al., 2004). These variables are transformed by processes, which take place in three diverse worlds that are recursively linked together (external world, interpreted world and expected world). Umeda et al. (1990) propose a similar representation scheme called function-behaviour-state in order to develop a Computer Aided Design tool to support the conceptual design. They give a clearer definition of the main concept (function, behaviour and state) and divide the model in subjective part and objective part. The function represents the bridge between human intention and physical behaviour.

Several studies has be done on the FBS model in order to create a more complete framework. Many authors have introduced other elements such as the context of use (Gero et al., 2004), the "working environment"(Deng et al., 2000), the users' needs (Chandrasekaran and Josephson, 2000; Cascini et al., 2012), goals, affordance (Brown and Blessing, 2005; Mayer and Fadel, 2009), alternative uses, failures and misuses (Del Frate et al., 2010; Cascini et al., 2010; Keuneke and Allemang, 1989), and so on. In particular, in time the focus has shifted more and more from the designer's perspective towards the user's perspective, taking into account his needs, goals and product perceptions.

Neglecting some of the elements of the most complete framework, this paper mainly focuses on the following elements: function, behaviour, structure, goal, environment and the user. In fact needs, failures, misuses etc. are not fundamental at the present stage of this case study where correlations between functions, behaviours and user's perception have still to be defined.

In our model the behaviour can be defined as the way the physical and chemical state of the product evolves in time and in its environment (Umeda et al. 1990). The function is closely related with the human perception of the behaviour; in fact, according to Sasajima et al. (1995), Umeda et al. (1990) and Gabelloni et al. (2011) it is the user's interpretation of the product's behaviour conditioned by the goal that the user himself wants to achieve by using the product. The structure of the product can be decomposed in features. Several definitions of feature has been provided for example by the FEMEX group (Weber, 1996) or in the field of functional analysis (Erden et al., 2008). However we synthesize the definition of feature as "the specific characteristics of a single part of the product, in terms of the geometrical entities and of the properties (e.g. of the material) that define it and characterize its behaviours" (Gabelloni et al. 2011). Almost all the papers in the literature propose mainly extensions of previous models only as purely theoretical constructs. Generally they do not provide any practical indication on how to implement themselves into the everyday practice of design. In fact the products analyzed in the literature are used only as case studies finalized to illustrate theoretical concepts. These few examples allow the user to understand the framework, but not really to use it in a clear and proper way in practice (Gabelloni et al. 2011). Therefore complete practical example of application of the FBS model to a real product is illustrated in Gabelloni et al. (2011), showing the complex relationships between functions, behaviours and physical features. Furthermore the authors try to create a link between the practical functional analysis and the theoretical FBS-based frameworks.

The aim of this paper is to present and test a methodology based on the FBS model concerning the design of a wine tasting glass by means of a real industrial case study. In this product the link between the design parameters (the structure), the performed functions and thus the behaviours is remarkable and clear. The variation of the wine perception of the user depends on the variation of the design parameters. In this kind of product the main design problems the designer has to deal with concern the strong correlation between the structure, the behaviours, the users' perception and the involvement of several senses that are strictly connected. Indeed if an expert sommelier tastes a wine in a black glass, scarcely and unlikely he would understand the real features of the wine. This is due to the lack of a visual signal, which dramatically alters the perception of experts. Therefore the study of the user's perception is fundamental to understand the product functions and behaviours, although the design of the glasses form is often guided more by aesthetic reasons rather than functional ones.

The analysis of all the behaviours and the determination of all the links is a really complex task. Thus the analysis of a single aspect is described below. This paper wants to present the analysis of a single chain composed of user's perception→product (wine+glass) function→product (wine+glass) behaviuor→ glass structure. Furthermore this study provides a new contribution to the tasting glass design, that is an interesting area connected with the popular food design. The paper is organized as follows: after a brief introduction about the method adopted, the study starts from the sensorial analysis through a panel of experts. An analysis of the behaviours associated with one of the most important function performed by the system is described in order to identify the main features (S) connected to the behaviuor. The next paragraph presents a methodology to acquire the geometrical feature of the glasses. Finally the discussion of the results and the conclusion are presented.

2 THE ADOPTED METHODOLOGY

This paper adopts a methodology for product analysis and re-design derived from FBS framework and Functional Analysis (Gabelloni et al. 2011), whose steps are shown in Figure 1. The design space is defined as the set of (i) a glass with (ii) a certain quantity of wine, and (ii) a user in (iv) a certain environment. The main functions that the product (glass+wine) carries on are those typical of a transparent glass with some peculiar functions for satisfying the needs of the particular users (Figure 1a). The first step of the methodology is a sensorial analysis, concerning the product (i.e. the glass structure and the wine), the environment and the user. In particular the perception of the user through his/her senses is analyzed (Figure 1b). That analysis is used to understand the effects of the behaviours on the wine and to filter the set of main functions (Figure 1c). Then the analysis moves on to understand which behaviours concur in performing the functions (Figure 1d). The analysis of the behaviours has to consider the entire system composed of the glass, the wine, the user and the environment. After, a correlation between the recognized behaviours and the features of the structure are identified (since B=f(S)), in order to understand how design parameters affect the behaviours (Figure 1e). The last step is to try to understand which are the optimal design parameters to re-design and improve the product (out of scope in the present work).

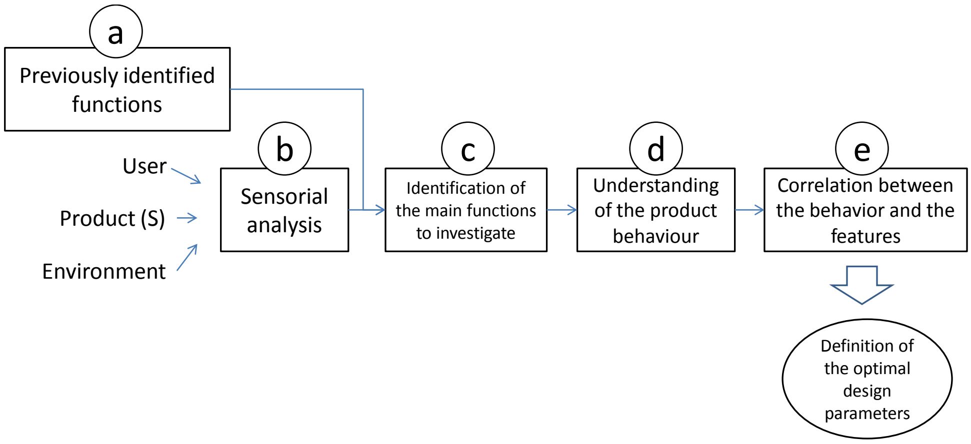

Figure 1. The adopted sequence of activities.

3 GLASS AND WINE: SENSORIAL, FUNCTIONAL, BEHAVIOURAL AND FEATURES ANALYSIS

Since the choice for a particular type of vessel could affect how the drink, and so on the wine, is perceived during consumption, many researchers have investigated the effect of varying the material, color and shape of the glass on the perceived aroma, taste and flavor of wine (Cliff, 2001; Delwiche e Pelchat, 2002; Hummel et al., 2003; Russel et al. 2005; Venturi et al., 2009; Shifferstein, 2009; Hirson et al., 2012). According to the more traditional physiological/chemical interpretation, different glass-shapes release different amount of volatile organic compounds from the wine's surface (Spence et al., 2012), therefore the glass shape may lend to a difference in flavor perception through changes in exposure areas (Delwiche and Pelchat, 2002) and the phenomena of evaporation, surface tension and capillarity could potentially be very different in different glasses (Peynaud, 2004, Vilanova and Vidal, 2008, Liger-Belair et al., 2012). Moreover, the increasing of the equilibration time seems to enhance the effect of the glass shape on both the headspace volatile composition and the aroma profile of the white wine (Hirson et al., 2012). Despite the possible significant effects of the glass shape on the sensorial expression of the wine, until now the existence of a clear correlation occurring between shape parameters and aroma sensory descriptor intensities and quality has not yet put in evidence (Hirson et al., 2012) and the results of the available researches appear to be contradictory (Spence et al., 2012, Hirson et al., 2012). Since the choice of the best combination of "glass type" and "wine tasted" appears to be an important factor for the definition of the wine sensorial profile (Cliff, 2001; Billing et al., 2008), an experimental research was developed to evaluate whether, when and how a type of glass could enhance or depress a specific well structured red wine taste sensation and to attempt to find any significant correlations among some shape parameters of the glass and the sensorial and chemical-physical profile of the wine.

3.1 The system, the environment and its functions

The object of the tests and the analysis are glasses for wine tasting (Figure 2). A particular red wine is poured in the glass and it is maintained in a well-ventilated quiet room. The tasting was carried out in the morning. The main elements of the environment which can interact with the wine are: the oxygen in the air that causes the product oxidation, the light that allows the user to see the color of the wine, the temperature and humidity of the room that influence the kinetics of the chemical reactions. The analysis of all the parameters interacting together is a really complex task, therefore some environmental conditions has to be settled.

From a functional point of view the glass shares many function with a standard glass (see Gabelloni et al. (2011)). Among them, the main functions related to the needs of such particular users can be selected. In particular those connected with the perception and with the chemical and physical evolution of the wine in the glass are[1]: convey+wine, move+wine, store+wine, convert+wine (oxidize), display+wine color, stabilize+wine, increase+exchange surface of the wine, transfer+thermal energy (from the environment to the glass and vice versa), transfer+thermal energy (from the wine to the glass and vice versa), insulate+wine, and convert wine in "gas" (evaporate). All the functions concerning the grasping, the handling, etc. are less influential in the perception of the wine and thus are not considered in this study.

3.2 Experimental results on perception and on physiochemical

With the aim to understand the influence of the glass on wine perception, five commercial different glasses (**Error! Reference source not found.**) were utilized by a group of ten well trained panelists to taste a red structured wine.

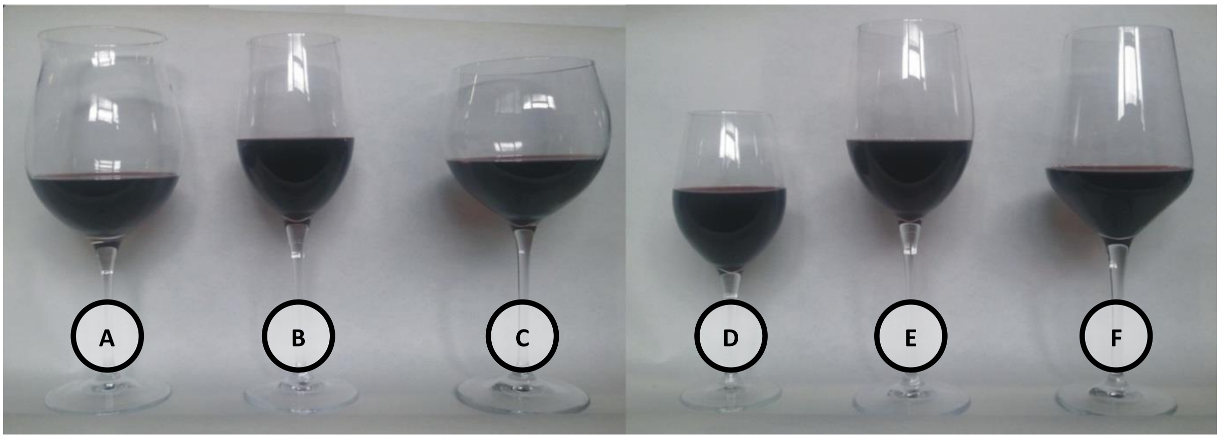

Figure 2. The chosen glasses

The wine was obtained utilizing '*Sangiovese*' grapes and aged in oak barrels. The sensorial profiles, obtained for the wine tasted in every analyzed glasses, were compared to each other and to that one expressed by the same wine when it was tasted in the "ISO" technical glass (Glass F). In order to put in evidence if the differences in sensory profiles are really depending on the physical properties of the utilized glasses, the evaporation rates were evaluated as a function of the type of glass at different equilibration times. In particular a quantity of 120 mL of a well structured red wine (Castello di Ama, DOCG), harvested in Chianti Classico region (Italy), was served in the six different wine glasses (Figure 2), supplied by "Bormioli Rocco e figlio" (Parma, Italy). The glasses capacity was determined measuring the mass of water (18º C), that each

[1]Functions are described in the standard form verb+flow according with (Hirtz et al 2002). Wine is used as flow instead of liquid to simplify the readability.

glasses can contain. To simulate a generic meal, the timing of the tasting sessions was fixed at 120 min with three different assessments (at t=0, 40, 120 min) performed at the same time in all the glasses.

3.2.1 Perception analysis of wine

The ten wine tasters (7 males and 3 females, between 30 and 65 years) ranked the wine contained in each type of glass on a scale of 0-10. They commented regarding the qualities, and evaluated the intensity and quality of each parameters in order to include visual, aroma, and taste impressions, as well as overall impression (Martin and Rasmussen, 2011**)**. Thus it was possible to obtain a sensory profile of the analyzed wine on the basis of the first order descriptors of color, flavoring and taste. All the assessments were repeated twice by the same group of panelists. The judgments obtained were evaluated by statistical analysis *(program R, version 2.10.0; 2 way ANOVA Cohort 6).*The results of sensory evaluations obtained at the beginning (t=0’) and the end (t=120’) of the tasting sessions can be usefully compared to find if and how the glasses differ each other as regard as the organoleptic properties assumed by the wine maintained inside them. With this aim, Principal Component Analysis (PCA) of each sensory attribute across six different types of glass was performed to illustrate graphically the correlations between ratings given to the different descriptors at two different times of tastings (t=0’; t=120’). In the PCA, all attributes were taken (Vilanova et al., 2009) so it was possible to have a complete picture of the sensory evaluations results. At both times, the first two principal components explained a percentage of the total variance greater than 90% (93.40 and 92.06%, respectively).

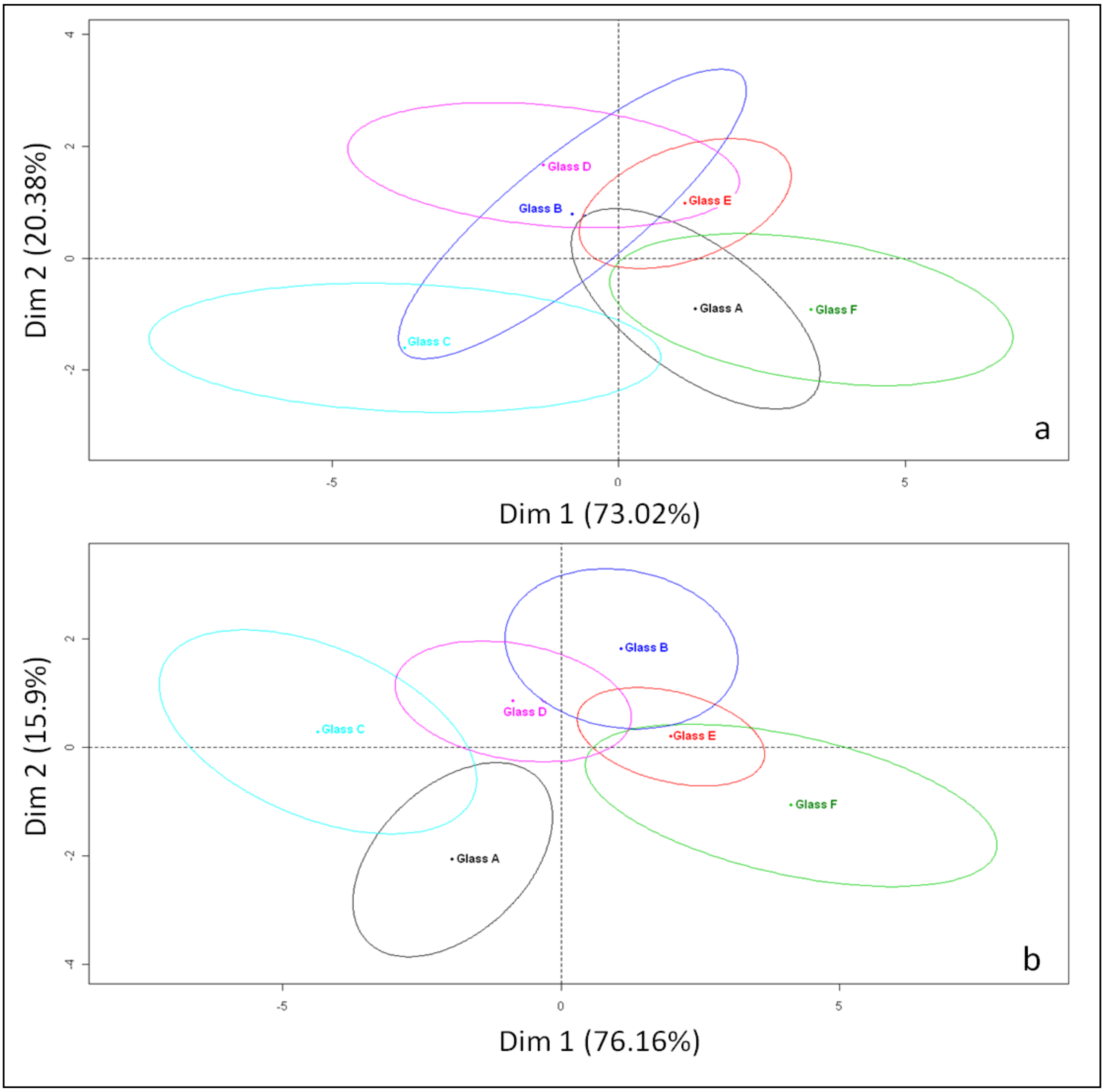

Figure 3.Confidence ellipses for the mean points at a) t=0', b) 120'.

In both the assessing sessions analyzed (t=0' and t=120'), the first principal component (PC1) was positively characterized by the overall appreciation, odor intensity, taste persistency, color intensity, odor harmony, frankness, equilibrium of taste attributes, having positive loadings. For the second principal component (PC2), the attributes color intensity, odor intensity showed positive loadings, while equilibrium of taste was loading negatively.

At the starting time of the tasting session, sensorial analysis results indicate the existence of some (but small) sensory differences according to glasses (Figure 3a). Conversely, After 120' of waiting, the results of sensory determinations changes greatly as a function of the different glasses utilized during the panel test (Figure 3b). The mean points of the confidence ellipses related to the glasses increased their distance one from another. In particular, with 120' of equilibration time, the wine contained in the Glass C is characterized by a sensorial expression significantly different than those obtained using Glasses F and only partially similar to that related to the Glass A. At this time (120') the best sensorial profile was showed by the wine maintained in Glass F, closely followed by that in Glass E. To sum up the characteristics of the wine are the result of the overall action of the behaviours. It is worth noticing that the data from the tests are an indirect measure of the effects of the system (wine-glass-environment) behaviours. Further analysis are necessary to decouple the different causes of the wine change.

3.2.2 Physical Analysis

The perception of a wine is a complex transfer function between a wide set of chemical physical parameters and the 5 senses. Indeed our sensory receptors are much more accurate than standard technical instruments used to measure the evolution of chemical-physical parameters. It is really hard to find any instruments able to measure the small variations that, on the contrary, can be easily recognizable by our senses. However several chemical-physical parameters, such as oxygenation, evaporation, concentration of phenols, acidity (titratable and volatile), sulfur dioxide concentrations (total and free) can be determined. Among them, the smell intensity is pretty complex to be measured through physical and chemical analysis but it could be correlated to the function **"to evaporate"**. In fact the loss of smell intensity of the wine is due to the evaporation and it is as a function of the glass parameters. Since the evaporation process is quite slow, the evaporation experiments have been prolonged for 120h in order to gather some reliable measurements. Thus such measurements have to be considered as a rough measure of what happens in 120'. Of course they are related to the geometrical features and the understating of such dependency is a key task to perform.
The evaporation rate of 120 mL of wine was determined in all glasses measuring the weight loss after 24, 48 and 120h (T=18°C and RH=80%). The histogram about the evaporated liquid is shown in Figure 4.

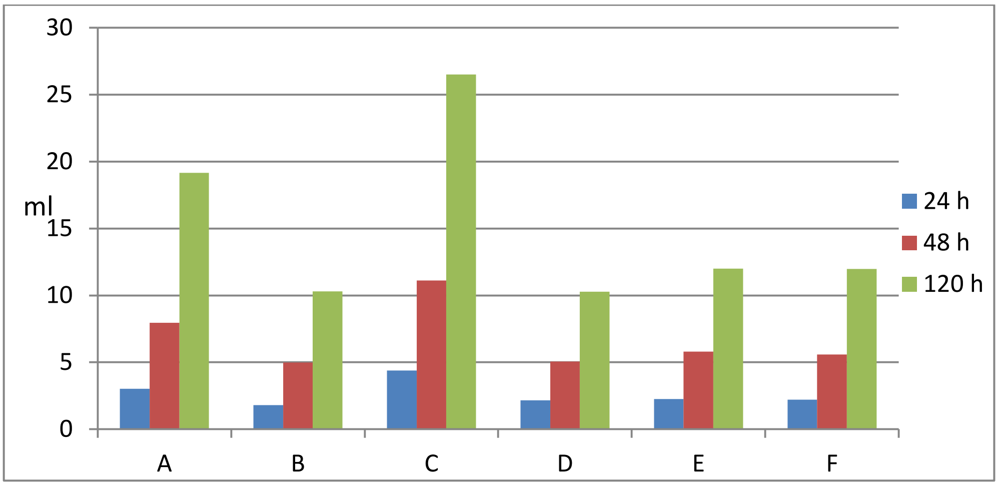

Figure 4. Evaporated quantity in ml in the different glasses at t=24h, 48h, 120h.

Figure 4 shows that glasses A and C present a very accentuated evaporation over time, while in the glasses B and D the evaporation is slower and lesser. These results are in accord with the previous sensorial analysis: indeed glass C, which presents a high evaporation, was one of the worst glasses, while glass F was one of the glasses that shown the best performance, and in fact the evaporation is medium-low. The physical and sensorial analysis allow us also to define a ranking of the best glasses for the tasting of the specific wine. In the next paragraph we will analyze how the behaviours are related to the physical characteristics of the different glasses.

3.3 The understanding of behaviours and correlation with design parameters

The evaporation function in a glass is a quite complex phenomenon where several physical effects concur. The free surface of the liquid evaporates, while a sort of stack effect draws the smell out of the glass. Starting from the observation from the physical analysis, in particular, we can assume the higher is the surface in contact with air (S_L) the higher should be the evaporation. Moreover the wider is the top surface of the glass (S_B) the higher is the smell coming out from the glass. Conversely, the bigger is the distance between top surface of the glass and the liquid surface (h), the higher is the confinement of the smell and lower its evaporation. In order to demonstrate such hypothesis an analysis of the dependency of evaporation on design parameters has been done. The rate of evaporation shows a great difference among the six glasses. The correlation among the data concerning evaporation and a suitable mix of the above mentioned geometrical parameters (S_L*S_B/h) shows a good linearfit (see Figure 5) at the three time intervals.

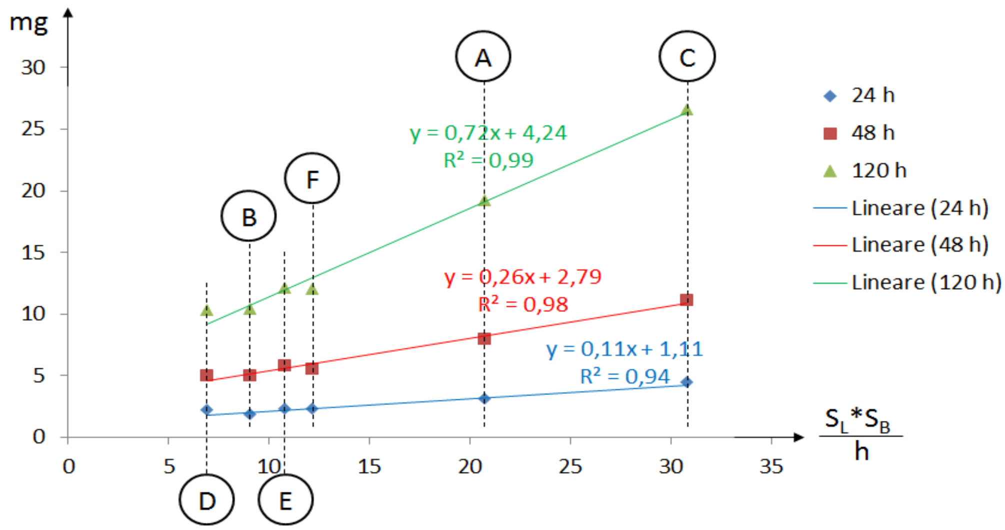

Figure 5. Dependency of evaporation on design parameters (SL, SB, h).

The analysis shown in Figure 5 prove that S_L, S_B and h are closely related to the behaviour associated with the evaporation phenomenon.

Wine oxygenation is one of the other parameters affecting the user perception. However, oxygenation is really complex and very difficult to be measured. Moreover the analysis of chemical parameters related to oxidation and of their evolution is not trivial. As an example when both experts and not experts detect a really strong variation in the wine no instrument is able to detect any quantitative data. Therefore the study of the oxidation will follow a different and more complex strategy, neglected here.

Thanks to the analysis of the behaviour a characterization of the glass design parameters is performed. Also the simple analysis of the geometrical characteristics is not trivial. In the next paragraph a method to acquire the geometrical features is shown.

3.4 Detection of the glass geometrical features through 3D optical acquisition

The methodology used for the 3D optical acquisition is based on an active stereo vision approach which uses a binary coded lighting (fringe projection) in order to capture three-dimensional views (*range maps*) of physical models (Barone et al., 2012a). The acquisition system used in this work has been specifically configured with the aim at digitizing the glass prototype by assembling an optical head and a turntable. The optical head is composed of a couple of monochrome digital cameras (CCD - 1280×960 pixels) and a multimedia white light projector (DLP - 1024×768 pixels). The turntable is based on a stepper motor and has a resolution of 4000 steps per revolution. The developed system allows the automatic digitization of physical samples with a lateral resolution of 0.4 mm an overall accuracy of 0.04 mm (Barone et al., 2012b). Figure 6 shows the hardware setup used for the digital reconstructions of the glass along with the result of the acquisition step. For the acquisition of the transparent surface of the glass a mat powder has been sprayed on the object. This treatment created a uniformly distributed thin layer (2-3 microns mean depth) of white material that guarantees optimal reflective properties when acquired by optical devices. The acquisition phase is carried out by two sequential object placements on the rotary table. The first position has been used to acquire the external surface of the glass. For this step 8 range maps have been automatically acquired and a total of 500 M points have been measured. The second position has been used for the internal surface of the glass. A total of 100 M points with 6 rotary stages has been acquired. The whole model of the glass has been reconstructed with the software Raindrop Geomagic®.

a) b) c)

Figure 6. Hardware setup (a) used to acquire the shape of the glass (b). Results of the acquisition step (c).

The model acquired has been then used as base for the reverse engineering design of the glass. A section of the measured surface has been created and used as sketch of a revolved extrusion around the mean axis of the glass. The resulting model is visible in Figure 7.

a) b)

Figure 7. Isometric view (a) and section (b) of the CAD re-designed model.

When the glass is acquired all the geometrical data are available and can be used to calculate the parameters (in the case of evaporation above: S_L, S_B, h) necessary for the correlation analysis. The acquisition of the geometrical data is crucial especially in the analysis of other behaviours, when accurate information about the geometrical values are necessary in order to understand their correlation with the behaviours themselves (e.g. the thickness of the glass is fundamental for the analysis of the exchange of the thermal energy).

4 DISCUSSION AND CONCLUSION

The starting point of the analysis was the perception analysis of the wine in six different glasses. The tests were performed by a panel of experts and allowed the research group to understand which were the glasses with the best performances with the chosen wine (as shown in Figure1). The variable factor map developed in Venturi et al. (2012) and the confidence ellipses show that the glass F is the best one, while the C is the worst. These results are qualitative assessments that take into account the perception of concurring and interacting parameters. The characteristics of the wine are actually enhanced or smoothed by the behaviours and thus functions performed by the glass. Therefore the idea is to decouple the functions and behaviours to study their effects on the wine. Among the identified functions, the function "to evaporate" has been chosen as one of the most important and impacting on the user’s perception. It is not the only important function to consider and indeed the present research is just one of the first step of the analysis. The analysis has showed that the glasses A and C favor the evaporation, while the others present lower values of evaporation. Such an analysis is aligned with previous perceptual analyses where users dislike a too high level of evaporation. Thus it proves that the evaporation is one of the fundamental behaviour to be analyzed. In addition, thanks to this two analysis it was possible to establish a ranking of the best tasting glasses.

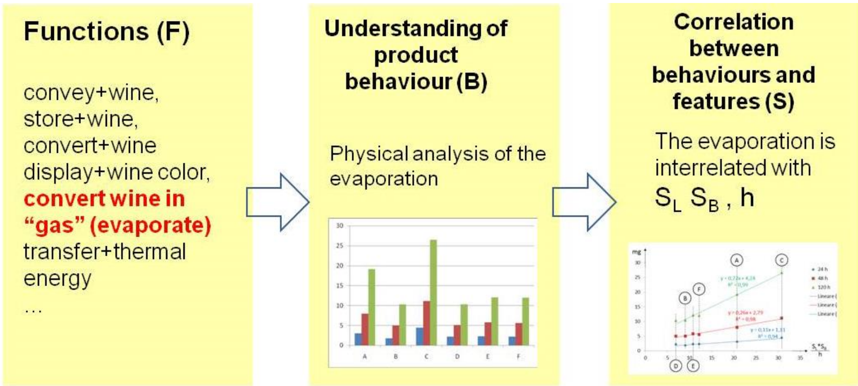

Figure 8 The core steps of the adopted method

After that the research tried to correlate such behaviour with the physical and geometrical parameters of the glasses. That was the first step to understand the key features to act on in order to redesign the glass. The analysis of the experimental results allowed to demonstrate that the higher is the surface in contact with air (S_L), the higher should be the evaporation. Moreover the wider is the top surface of the glass (S_B) the higher is the smell coming out from the glass. Conversely, the bigger is the distance between top surface of the glass and the liquid surface (h), the higher is the confinement of the smell and lower its evaporation. This results show the strong link between functions, behaviours and structures as presented in various FBS models. Moreover, even if the case of the redesign of a glass seems very simple, the interrelations among the numerous behaviours and the glass features demonstrate how complex can be their interactions and their effect on user perception. Finally a method to detect the geometrical design parameters, using a 3D optical acquisition system, has been shown.

One of the main strength of the proposed methodology is the integration of the sensorial analysis with the engineering design. It could be extended first of all to the design of glasses for cocktails or hard liquors, glass bottles as well as all the products where the interaction between users' senses and the product itself is strong.

Future works will extend the present study to other functions and behaviours of the tasting glass (as for example the oxygenation) in order to identify the correlation among all the behaviours and to assess the optimal value of the different design parameters. Furthermore to complete the study a double PCA can be performed: one for the assessing perceptive variables and another with the glass features. Their comparison can help in assessing the full set of correlations between perceptual feelings and physical/geometrical features.

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