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Multivariate Analysis in Design

Gilson Braviano[1], Sergio Scolari[2]

[1] *Federal University of Santa Catarina, Florianópolis, Brazil*
gilson@cce.ufsc.br

[2] *Federal Institute of Santa Catarina, Florianópolis, Brazil*
scolari.sergio@gmail.com

Abstract. The identification of certain geometric-visual patterns associated with real situations can be useful in generating solutions to fundamental problems. In many cases, the regularities in these patterns can be brought to light through a statistical approach. Aiming to highlight the power of quantitative research in the fields of humanities and arts, this article describes three applications of statistical techniques of multivariate analysis in Design. The third one is presented in more detail, addressing a relevant and contemporary challenge, contributing to the generation of more efficient and inclusive interfaces for search systems in sign languages.

Key Words: multivariate statistics, design, deaf people, search systems

MSC 2020: 62H30 (primary), 51

1 Introduction

As a language, mathematics is useful for describing, comparing, analyzing and proposing, and this can be done from an arithmetic, algebraic, geometric or trigonometric approach.

With these different perspectives, the mathematician seeks to identify real or imaginary, visual or mental regularities. The patterns found, when examined in an abstract way, allow the formulation of theories applicable in many fields of knowledge, which can even lead to the development of a new branch, as happened with statistics.

Thus, concrete problems, relevant in the field of humanities, can benefit from advances in statistics to identify inclusive solutions, better adapting people to their environments.

The complexity of research involving human beings considers the behavior of multiple variables simultaneously. As a result, the less representative variables can be eliminated, so that the others constitute a clearer statistical model, in which previously unknown relationships emerge from invisibility.

This article follows this line, approaching the field of multivariate statistics as a powerful contemporary tool capable of producing geometric-visual information. This type of information will be exemplified in the following section, based on two applications in the field

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of design, which allows demonstrating its usefulness in identifying and proposing solutions by professionals and researchers working in the humanities field. Another application will be described in the third section, in greater detail, evidencing the contribution of a research to the generation of more efficient and inclusive interfaces aimed at search systems in sign languages.

2 Multivariate Analysis in Design

Working with multiple variables concurrently is a complex task. It has been facilitated in the last two decades, thanks to the growing number of statistical software with specific modules for multivariate analysis. The different techniques allow the treatment of more than two variables, correlated with each other or not. In addition, the variables can be quantitative or qualitative, and one can explore their joint performance or the influence of each one on the others.

The main parameter for the adequate choice of the multivariate statistical technique is the presence or absence of some dependent variable, which can be explained as the result of the relationship between some independent variables. For [1], the most common techniques are Multiple Regression, Discriminant Analysis, Logistic Regression, Factor Analysis, Cluster Analysis and Multidimensional Scaling.

More recently, a search carried out by [11] in the Scopus, Web of Science, Scielo and Google Scholar databases showed that 71% of the searches using multivariate techniques were in Medicine. When particularizing this search for use in Design, the filter returned less than 0.1% of the results obtained previously. This result only reinforces that this field focuses its research on qualitative approaches and, when the use of quantitative processes occurs, it rarely articulates multivariate relationships of similarity, dependence, interdependence and prediction. The most recurrent multivariate technique was the Multivariate Analysis of Variance – MANOVA –, but Factor Analysis, Logistic Regression, Multiple Regression and Cluster Analysis were also observed.

In particular, Cluster Analysis and Multidimensional Scaling generate specific charts to translate what the variables together are reporting. In the first case, dendrograms are used; in the second case, perceptual maps are usefull. In both, the reader obtains visual information from the positioning of the elements in the figures, supported by numerical indices based on analytical geometry. Thus, multivariate analysis, traditionally associated with only few fields of research, is now more widely adopted. In the specific case of Design, where forms and positioning are widely used in the conception of ideas and presentation of design solutions, the applied mathematics through multivariate statistics emerges as a differential, presenting itself as a powerful contemporary quantitative tool.

While Cluster Analysis generates a visualization of groups with a strong degree of internal similarity, that is, elements with similar characteristics in known variables, the Multidimensional Scaling technique produces an image related to the perception of a set of objects, based on implicit dimensions that people have about these objects. These dimensions are not restricted to physical ones (size, temperature or weight, for example) and may also represent importance, modernity, usability, pleasantness, and trust, among many others. By judging the degree of similarity between several pairs of objects, the technique allows mapping their relative distances and positioning them in a perceptual map, usually two-dimensional. With this map, the interpretation of the implicit information, represented by the two dimensions, can be carried out.

Figure 1: Images from fashion shows, adapted from [18]

In the last decades, good books published in English have approached this and other techniques, in a theoretical and practical way, such as the classic [3]. A simple internet search will bring up several of these books. Its production in other languages also increased. As an illustration of this, the Portuguese language has important references, such as [1], [4], [6] and [10]. Thus, with adequate literature and software capable of supporting data analysis, the use of multivariate statistics in the area of Design is increasing, as the following examples illustrate.

2.1 Subjective reading in Fashion Design

When considering the importance, for the Fashion Designer, of a good visual reading and adequate sensation transmitted by the garments, [18] evaluates how these professionals conduct the subjective reading of the elements present in the pieces. The study was based on eight pairs of fashion show images (Figure 1), which represent the four main design elements: line, color, silhouette and texture (vertical and horizontal lines; silhouettes with volume in the lower and upper regions; vibrant and complementary colors, but also analogous; and textures with a more structured and shiny surface, or light and opaque). The data were analyzed using Multidimensional Scaling and the research was also applied to non-designers, in order to verify how the general public perceives the same elements in clothing. A total of 84 people participated in the research, 46 of them non-designers and 38 designers. They assigned similarity values to different pairs of looks.

The perceptual map generated from this study is shown in Figure 2. The position of each look is almost the same for designers and non-designers, generating a very strong and positive correlation ($r = 0.986$, $p \leq 0.001$). This implies that the two groups identify the looks in a similar way. From the generated perceptual map, it was found that the two subjective criteria used by the respondents were fashion communication (conceptual/abstract looks versus commercial models) and style temporality (more classic and timeless looks versus more contemporary and exotic models). In the horizontal dimension, the looks on the left are more conceptual, expressing abstract aspects of clothing, while those on the right are commercial models, more usual and related to commercialization. In the vertical dimension, the looks at the top are more classic/timeless, while those at the bottom represent more contemporary and exotic models. From this knowledge about how people implicitly categorize garments, the professional will be able to abstract the inspirational visual elements. Then it will be possible to materialize them in the development of fashion collections.

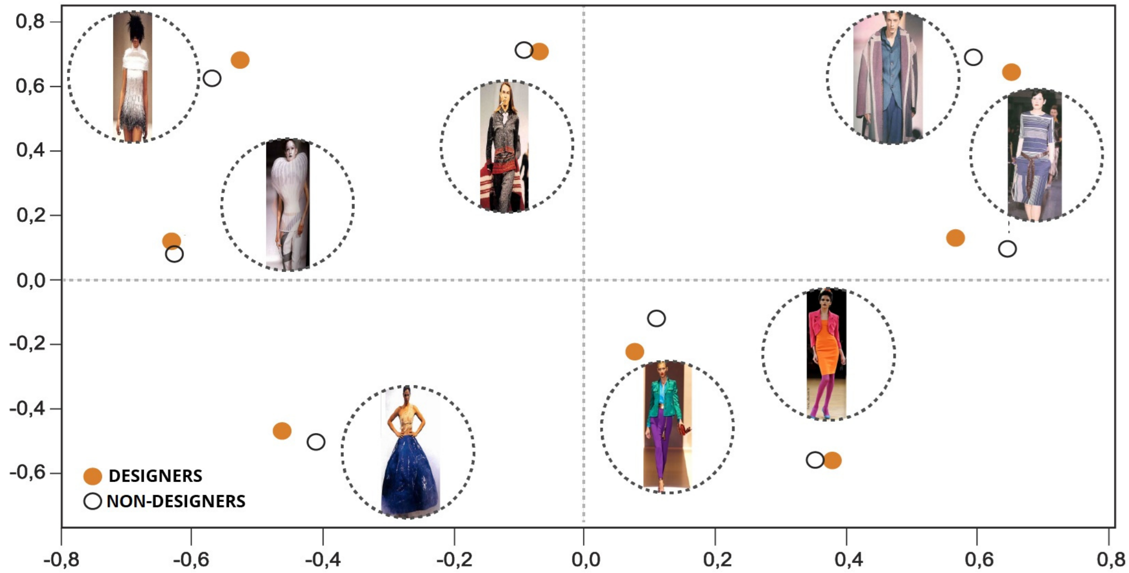

Figure 2: Perceptual map, adapted from [18]

2.2 Perceptions of the characteristics of typographyc fonts

Another application, developed by [7], considered that the communication effectiveness of a graphic piece requires that the graphic elements correctly translate the concepts and ideas to be transmitted. Among them, typography provides an adequate structuring of written language, contributing to the clarity of the final composition. This study, whose analysis was also carried out by Multidimensional Scaling, aimed to identify the perception of the non-designer public about the main characteristics of typographic fonts, in comparison with the classifications used by designers. The research was based on eight typographic fonts (Figure 3) belonging to four different classifications, arranged in pairs, without indication of classification or nomenclature, for the subjective judgment of similarity between them. As in the previous example, an ordinal Likert scale was also used, with values from 1 to 5. The 28 possible combinations were submitted to 37 non-designers and 18 designers, all volunteer participants.

The results showed a very strong and positive correlation ($r = 0.929$, $p \leq 0.001$) in the way the two groups classify these typographic fonts. From the generated perceptual map (Figure 4 shows the one from designers), it was identified that the implicit dimensions used for the classification are its mechanization (mechanized versus organic) and formality (classical versus relaxed). In this sense, designers themselves judge typefaces by their general appearance and the abstract sensations they denote, and not by their technical characteristics, in the same way that non-designers do.

The two examples presented reinforce the importance of using quantitative analysis in the fields of visual communication and the arts. The geometric representations that the human brain makes when positioning different elements, one in relation to the other, allows a researcher to identify the implicit criteria used in judgments, that is, those that are most important and are not represented in the technical categories.

In this context, a study that adds Multidimensional Scaling to Cluster Analysis is presented below. This study aimed to generate a proposal for a more efficient and inclusive interface for search systems in sign languages, based on the perceptions of deaf people about handshapes.

Figure 3: Representation of the eight fonts, in pairs, considering different typographic anatomies: serif (Times New Roman and Bree Serif), sans serif (Helvetica Neue LT Com and Impact), decorative/display (Rosewood STD and Heartland Regular) and handwriting (Comic Sans MS and Satisfy), adapted from [7]

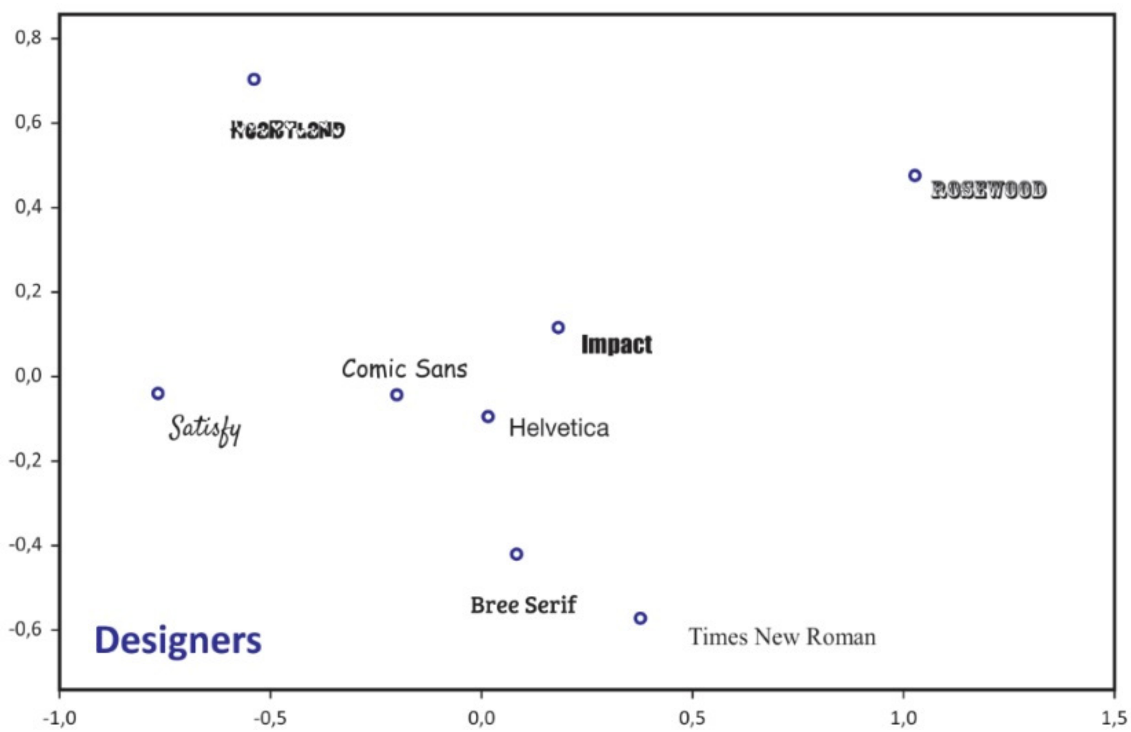

Figure 4: Perceptual map related to designer perception, adapted from [7]

3 Multivariate statistics in the design of sign language online dictionaries' search interfaces

Deaf people belong to a cultural and linguistic community – that may include family members of deaf people, sign language interpreters, and individuals who work or socialize with deaf people, including people of varying degrees of hearing loss – who use sign language as a mother tongue or natural language to communicate. Deaf people have their own culture, including beliefs, attitudes, history, norms, values, literary traditions, and art. According to [20], nowadays there are 70 million deaf people in the world, from which approximately 56 million, that is, around 80%, receive no education.

One of the tools used in deaf people's education is sign language dictionaries. Initially, sign language dictionaries were bilingual wordlists used by parents and teachers to improve communication with deaf children and deaf students. These dictionaries were ordered alphabetically or thematically (or both) and unidirectional from the spoken to the signed languages [19]. Nowadays, with digital media – and the ability to continuously add new information, and the detachment from printed page limitations such as production resources and page sizes –, dictionary creators began rethinking dictionary designs in various levels, experimenting with new ways of representing signs and their parameters [5].

While search interfaces for spoken languages can be quite simple, with few graphical elements and a text field to insert words or characters, in sign language search interfaces, elements representing signs and their parameters are numerous. In the design process, appropriately laying out these elements is a complex issue to resolve. Although there are notation systems used for indexing and searching sign entries – such as the Hamburg Notation System for sign languages [8], SignWriting (`https://www.signwriting.org`), and the phonologically based Stokoe notation system [16] –, they are scarcely used in search interfaces. With no generally accepted orthography, several distinct representational strategies can be found across dictionaries.

One strategy to determine search processes and interface designs is using phonological parameters of signs. At the phonological level, the sublexical structure of signs, that is, the formal aspects of signs below the syllabic level, can be described and analyzed. According to [9], five phonological parameters can compose the structure of a sign: handshape, location, movement, orientation, and non-manual components. The studies described in this section examined handshape, which has the most complex internal structure and visual components.

Handshape (or designator) is the configuration of the hand or hands in a sign which makes a movement at a location [15]. Linguistic analyses have further spelt out handshape in terms of constituent properties. As specified by [17], the minimal set of features that can generate distinctive handshapes can be divided into two categories, namely, finger selection and finger configuration. Finger selection regards the number and the choice of fingers that are salient in the execution of the sign. In specifying finger selection, fingers can be unselected, when they may only be folded into the palm or extended, or selected, when they have specific properties controlled by the configuration features, varying on their degree of flexion (bent, clawed or curved), spreading (spread, non-spread or crossed), or aperture (open or closed).

Following the idea of bringing native signers' visual perception into the layout design of handshapes, [12] aimed to make explicit dimensions they use to assess handshapes similarities and, for this purpose, used a multidimensional scaling analysis. This exploratory analysis was designed according to the decision-making diagram suggested by [2, pp. 428–429] and was composed of three basic steps. The first one was to collect data about objects' similarities, for

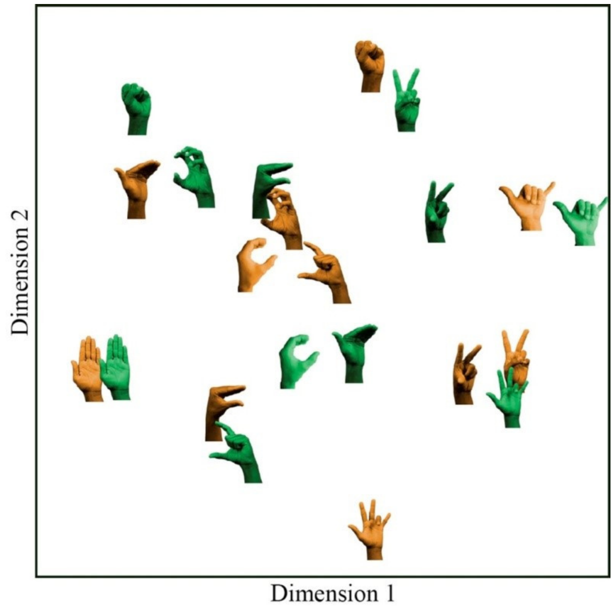

Figure 5: Overlapped perceptual maps

which it was developed a multilanguage questionnaire. A detailed description of this process, including a discussion about methodological issues, can be found in [13]. The second step was to estimate objects' relative positions in a multidimensional space, creating perceptual maps generated by a process of Multidimensional Scaling. Finally, the last step was to identify and interpret the multidimensional space, making explicit the evaluative dimensions.

Acording to [12], perceptions from 13 Libras (Brazilian Sign Language) native signers and 16 NGT (Dutch Sign Language) native signers were gathered. Data were analyzed using aggregated analysis, with aggregation happening before scaling the data. Similarity answers used mean values, divided into two matrices: one for Brazilian participants and one for the Dutch. To visualize handshapes relative distances, considering the selected data, it was run a multidimensional scaling analysis using IBM SPSS Statistics 23®. Perceptual maps' dimensionalities were determined by subjective evaluation after visual inspection and were defined as bi-dimensional. The map used for interpretation, shown in Figure 5, overlapped both perceptual maps and had handshapes' names substituted by their images. To distinguish Libras' handshapes (green) from NGT's (orange), they were coloured differently.

Dimensions identification process adopted subjective procedures, with analyses being carried out by the researchers. As mentioned by [12], the results denoted a reasonable coherence between the two groups of participants' assessments. The objects were spread out on the map's area, with handshapes represented by angled orientations concentrated towards the center of the map and handshapes represented in forward orientations located near the map's boundaries. The handshape pairs assessed with similar relative distances were examined individually.

Interpretation of perceptual maps led to identifying dimension one as spreading and dimension two as opening. Spreading can be interpreted as the change in distance between fingers and opening as the distance between fingers and the wrist. Although these dimensions may have similarities with the standard sign language phonological features, they are not interchangeable. As stated by [12], a noteworthy characteristic of these dimensions recognizes the intermediate steps between the binary classifications. While in linguistics, most

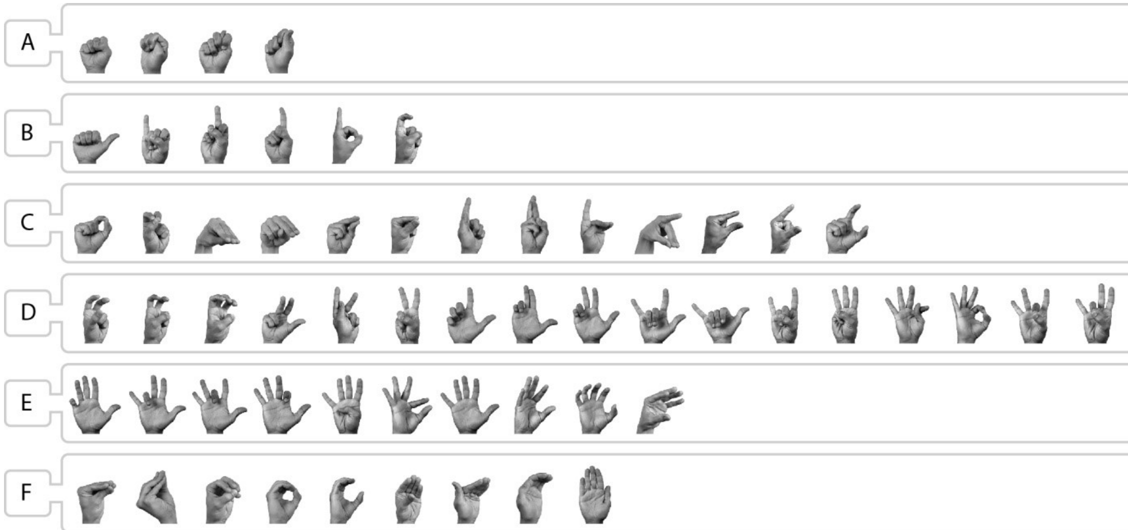

Figure 6: Handshape clusters

specifications are binary, for the perception of visual similarity, these values could be interpreted as poles to scales with intermediate measures. In this context, the small changes in hand-internal movement registered by each distinctive handshape become visual clues for helping native signers to evaluate the stimuli.

In a following study, [14] used spreading and opening along with the number of prominent fingers as variables in a Cluster Analysis, aiming to create a taxonomy for sign language handshapes based on their visual similarities. Observations of these three variables were collected for a set of fifty-nine handshapes. To determine the proximity values for spreading and opening an online questionnaire to be answered by specialists in sign language linguistics and sign language/bilingual interface design was designed. Researchers and lecturers, professionals such as sign language interpreters and web designers, native and non-native signers of NGT and Libras, from Dutch and Brazilian institutions, were invited to participate. The questionnaire asked specialists to evaluate each handshape's degrees of spreading and opening using a five-point scale. Finger prominence was determined by a six-point scale, where zero represented no prominent fingers and five represented all fingers prominent. However, as finger prominence showed to be an objective dimension, the researchers attributed its values through visual inspection.

As specified by [14], a hierarchical clustering algorithm using an agglomerative method was run, experimenting with different linkage methods: average between groups, average within groups, single, complete, centroid, median, and Ward. Handshape images were added to the resulting dendrograms and organized according to clustering order to inspect the groups' visual qualities. When using the Ward linkage method, the clustering algorithm balanced the number of groupings, number of objects within groupings, and internal homogeneity better than the other methods mentioned above. The final classification structure, consisting of six clusters, was determined after two iterations of the algorithm. Although groupings appeared considerably homogeneous in this solution, there was still an amount of visual entropy left by the order objects assumed within them. Consequently, handshapes were re-ordered to achieve a sense of shape gradation and create an impression of progression. Figure 6 expresses that study's final taxonomy structure.

By designing handshapes according to perceived visual similarity, one shifts the focus from abstract classifications and representations (letters or names) to the actual nature of visual stimuli. Ultimately, as native signers are expected to rely on the visual features of signs, the proposed taxonomy can be seen as an option for displaying handshapes in a way that requires less metalinguistic skills to support their actions when searching online dictionaries.

4 Final considerations

A common way for mathematics to be applied to the field of arts and humanities is by using geometry as a language. However, the geometric-visual patterns associated with a real situation are not always known, so they need to be identified in order to be used.

This article illustrates how certain regularities can be brought to light through a statistical approach, generating images of perceptual diagrams or dendrograms. The analyses of these images create valuable subsidies for the decision-making process. In this context, this article emphasized two techniques of multivariate analysis: Multidimensional Scaling and Cluster Analysis.

Two applications of Multidimensional Scaling were briefly described. Then, the procedures of a research that contributed to the design of more efficient and inclusive sign language search interfaces were outlined. That investigation combined the two multivariate statistics techniques mentioned above, to create a handshape taxonomy based on perceived visual similarity.

This article was limited to describing only three investigations concerning the use of mathematics in design research methods. These descriptions focused on how the multivariate statistical techniques were applied rather than the outcomes of those studies.

As quantitative approaches in Design research are still modest, the contribution of this work lies in highlighting its impact by gathering design studies that applied multivariate statistical analyses and showing their effect on developing innovative solutions.

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