FORM FOLLOWS DATA: A METHOD TO SUPPORT CONCEPT GENERATION COUPLING EXPERIENCE DESIGN WITH MOTION CAPTURE.

Camere, Serena (1); Caruso, Giandomenico (1); Bordegoni, Monica (1); Di Bartolo, Carmelo (2); Mauri, Duccio (2); Pisino, Enrico (3)
1: Politecnico di Milano, Italy; 2: Design Innovation; 3: FCA Group

Abstract

Human movements express non-verbal communication: the way humans move, live and act within a space influences and reflects the experience with a product. The study of postures and gestures can bring meaningful information to the design process. This paper explores the possibility to adopt Motion Capture technologies to inform the design process and stimulate concept generation with an Experience Design perspective. Motion data could enable designers to tackle Experience-driven design process and come up with innovative designs. However, due to their computational nature, these data are largely inaccessible for designers. This study presents a method to process the raw data coming from the Motion Capture system, with the final goal of reaching a comprehensible visualization of human movements in a modelling environment. The method was implemented and applied to a case study focused on User Experience within the car space. Furthermore, the paper presents a discussion about the conceptualization of human movement, as a way to inform and facilitate Experience-driven design process, and includes some propositions of applicable design domains.

Keywords: Conceptual design, Motion Capture, User Experience, Data visualization, Body Tracking

Contact:
Serena Camere
Politecnico di Milano
Department of Mechanics
Italy
serena.camere@polimi.it

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

Human movements are gestural representations of how we perceive the world around us. The way we interact with objects is expressed by the postures we take and the actions we do. From this perspective, gestures are bodily expressions of a system of meanings: in other words, *"my body appears to me as an attitude directed towards a certain existing or possible task"* (Merleau-Ponty 1962). Postures and gestures differ from each other: while postures are a kinaesthetic adaptation to a space or a product, gestures articulate a specific meaning in the way we move our body. The ability of human gestures to express subjective experiences is rapidly becoming a topic of interest in the Experience Design domain. An analysis of how people move around (and relate with) objects can help designers in exploring the rich, non-verbal communication of users' perceptions. In this way, human movements are seen as raw data that can inform the design process and sparkle new ideas.

Motion Capture is considered the most accurate method to track human movements and reconstruct them in the virtual 3D environment. It offers a rich amount of knowledge on the quality of human gestures, including 3D information on the position, the movement speed, the orientation, the fixation (i.e. the time spent by the user in a certain position) and the frequency of a movement. This technology is commonly employed, coupled with Virtual Reality technologies, at the end of the design process to assess aspects such as ergonomics and usability (Bordegoni and Caruso 2012; Du and Duffy 2007; Chaffin 2002; Mengoni et al. 2008). However, it is scarcely used with an Experience Design perspective. This can be motivated also by the computational form of the quantitative data produced by Motion Capture systems. The information results largely inaccessible for designers, who need a flexible and clear representation in a modelling environment. For instance, to effectively support the design process, motion data can be elaborated to suit 3D modelling software tools. Yet, no extensive method was found in literature addressing the visualization of human movements for concept design purposes. This research introduces a systematic process to manage motion data and to use them as a generative input for the design process. The method was developed through a case study in the automotive sector, in collaboration with a design agency (Design Innovation) and the R&D department of Fiat Chrysler Automobiles Group (FCA Group). This paper presents the outcomes of the case study, highlighting the benefits and limitations of the method, and the issues concerning the visualization of motion data. In the final remarks, we will reflect on future research possibilities and other fields of application for this method.

2 STATE OF THE ART

The study of human movements can be conducted by several means, either with a qualitative or a quantitative approach. These differ on knowledge claims, strategies employed and nature of data. A qualitative study, such as the analysis and the interpretation of the human movements recorded in a video, can provide insights to generate new concept ideas. However, these insights cannot be converted in objective data useful to model the new concept. The quantitative approach, instead, allows to record human movements in a numerical form and then to reconstruct those movements in a virtual 3D environment. While the qualitative output is subjective and highly personal, the quantitative approach guarantees comparable data and aims at statistical validity. Hence, they can complement each other, providing information on different levels of the User Experience (UX). The horizontal attitude of quantitative methods gives a specific and punctual knowledge on a broad sample of participants. Qualitative research uses instead a vertical approach to dig deeper in users' latent desires and needs (Visser et al., 2005). For their complementary nature, the traditional dualistic perspective faded over the last years, leaving room for a mixed-methods approach (Creswell, 2003). Numeric information (i.e. measurable data) is collected simultaneously or sequentially to text information (i.e. interviews, etc.). In this way, it is possible to obtain rich patterns of user experiences, and to specifically aim at improving them through a novel design. This approach, namely (User) Experience Design, has evolved during the last decades, with a core of several methods constituted to depict users' desires and expectations. Many classifications are available in literature, providing categories and criteria to select the most appropriate tool (Maguire, 2001; Isomursu, 2008; ENGAGE, 2006; Vermereen et al., 2010; Gatti et al., 2014). According to the kind of results needed, it is possible to choose between an explicit or an implicit approach, a quantitative or qualitative method, etc. (Gatti et al., 2014). Furthermore, Experience Design methods can affect the design process at different stages. Some of them support the evaluation phase of a concept, to help assessing the best design (Albert and Tullis, 2013; Desmet, 2002). In other cases, users are involved at the beginning of a project, aiming to depict a complete pattern of their experiences (Hassenzahl, 2010). This information is then used to nurture and inform subsequent design actions. Several methods fall in this category: they all share a generative attitude, to provide designers with deep information on user-product interaction (Gaver et al., 1999; Visser et al., 2005). Among them, video-recorded user observations are one of the most common ways to infer insights on the UX. From videos, designers can understand the critical issues of user-product interaction to face during the design process. To do this, beyond the interview analysis, designers can focus on users' movements as an expression of specific experiences. However, this understanding of video-recorded data can be based only on their subjective interpretation and limited in the output and viewpoint of the recording camera. Tracking the human movements in the 3D environment, instead, provides more information on the nature of gestures, in the form of numeric data that can be processed with a well-defined procedure. In this study, we have coupled Motion Capture technology and Experience Design techniques to retrieve information on user movements, and subsequently use them as input for the design process. The final goal will be the definition of a method that integrates traditional user observations with more accurate information on human movements.

2.1 Applications of Human Motion Data in (Interaction) Design

Human motion data recently gained some attention in the field of Interaction Design, Architecture, Art & Humanities. Human movement is a non-verbal expression of how we perceive a space. Besides, it is not only a matter of study for architects. We move around products, we alter our postures and we gesturally interact with them. Products suggest us how to use them through their affordances (Norman, 2002), and these influence directly our actions. The movements we perform to interact with the object define the boundaries of a space where subject and object are interrelated (i.e. the *space of interaction*). The notion of spatial interaction comprises a *spatiality of sensation*, which should be distinguished from a *spatiality of position* (Merleau-Ponty, 1962). The possibility to capture this embodied experience inspired several studies on the topic, which adopt Motion Capture technologies. However, a critical point crosses all researches. Tracking the human body movement generates computational data that, due to high accuracy of the optical technology extensively used for this purpose, can be excessive in their informative nature. The raw data imported from the Motion Capture software tool into the 3D modelling environment need to be processed and analysed to become explicit to designers. Moreover, even when they are examined with a systematic method, the selection of the criteria and the data representation are tricky steps to solve. A reference standpoint is the analysis on motion studies carried out by Gavrila (1999), who positioned several approaches, from Computer Graphics to Biomechanics, according to the technique of visualization. From an art perspective, the project Bodycloud (Perret, 2010) performed a capture of a dancer to generate a sculpture visualizing his graceful movements. The work is rooted in the figurative arts, yet it provides a large set of references of how visualization of movement has been tackled in the artistic domain. Vroman et al. (2012) adopted a reverse engineering of human motion as a starting point for architectural design. Considering movement in relation to time and space as a way to experience architecture, they visualized the negative space obtained by subtracting the movements from the model of a space. Another study (Hansen and Morrison 2013) addresses more specifically the topic of motion visualization, suggesting a semiotic approach to understand the properties and peculiarities of movement data. The authors provided a Movement Schema in which they relate the core modalities of movement to their specific characteristics and to the corresponding best visual description. They developed a tool to visualize human movement through the use of Kinect© (Kinect for Windows, 2014). From these examples, some general considerations can be made. All the studies stated the necessity to leave freedom of interpretation to the designer, by not over-imposing meaning to the visualization of movement data. Additionally, there is no clear agreement on which modalities of movement should be represented and, more important, how they should be characterised visually. On this matter, we propose that the semiotic approach is integrated with an infographic one, treating the core modalities of movement as variables to display. In this paper, we introduce a method to make sense of motion data and to visualize them in a 3D virtual environment.

3 THE CASE STUDY

To clarify how we can use the visualization of spatial interactions, and whether it is possible to use it as a design material, we established a case study in collaboration with Design Innovation, a design agency based in Milan, and Centro Ricerche Fiat (CRF), the R&D department of FCA Group. The task was the redefinition of the car interiors for passengers aside the driver seat. The passenger seat is usually designed as the symmetrical counterpart of the driver seat, sometimes even lacking some features (such as the lumbar support). However, driver and passenger have highly different needs in terms of comfort, safety and freedom of movements. The automotive company asked then for a user-centred research to generate new concepts of the passenger seat with a special focus on comfort and UX. The development of the case study required a number of actions, some of which iterative. Figure 1 shows the subsequent phases of the project.

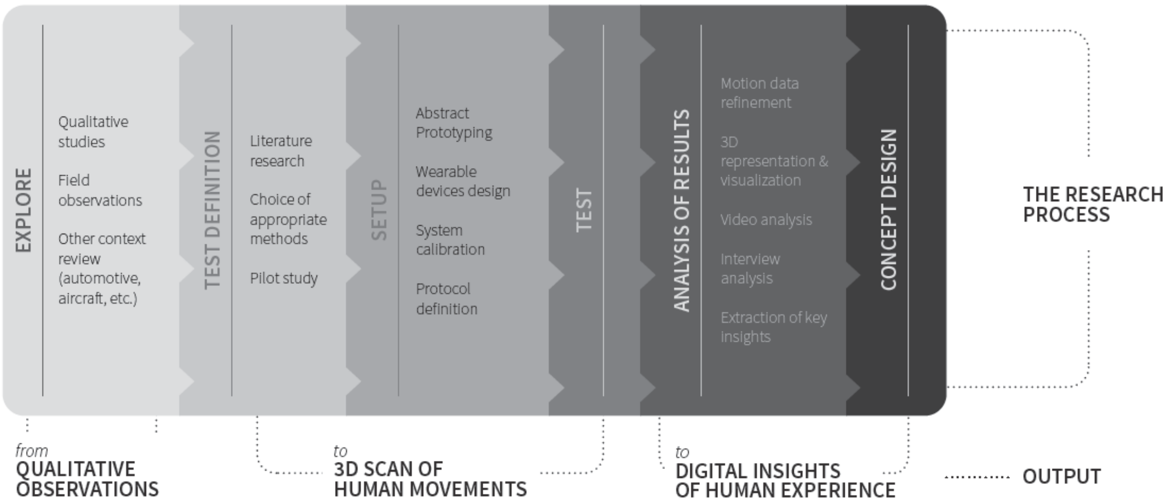

Figure 1. Methodology of the case study.

As a preliminary approach, the design team conducted a quick test in field-research modality, observing users in a real context. This preliminary observation was meant to identify the themes (Dorst, 2011), corresponding to users' needs, to be further explored in the study. The observation was carried out with 9 participants, 5 male and 4 female, video-recording them with a frontal GoPro© (GoPro Official Website, 2014) camera and one hand-camera in the back seats. Participants were brought on a medium-length journey (average 40 minutes), after which they were interviewed about the level of comfort, their needs and their expectations. As in the emotion measurement research, this approach is considered the less intrusive in the experience itself, while still allowing us to collect rich records of experience (Laurans, 2011). Through these first results, we were able to determine five themes: (1) the assessment of comfort in posture; (2) the interaction with either people or objects in the back seats; (3) the placement of personal items, such as bags, coats etc.; (4) the interaction with smart devices; (5) the users' perception of the space. These problem areas were established as correlated to alterations in posture and gestures. For this reason, they will constitute the tasks to deal with during the following user tests. The use of Motion Capture data is expected to add value to this first track of tests, for it supports the analysis of UX with a 3D representation of human gestures while interacting in specific tasks. Conversely, without this preliminary stage it would have been difficult to understand how to build the procedure to conduct the interview.

3.1 Test definition & set up

The set-up required a number of actions to prepare the tests properly. The first issue to face was to create a favourable environment for the tests. Clearly, Motion Capture system required the tests to be run in a laboratory, but the necessity to partially recreate the physical limitations of the car was entailed. However, it was not possible to use a car's framework in order to prevent occlusions during the capturing activity. To cope with the delicate phase of designing a light environment that will both make the user comfortable and avoid inconsistent or poor results, we adopted the Abstract Prototyping technique from

Human Centred Design research (Ideo, 2008). Abstract Prototyping involves the creation of a rough prototype of an artefact, which is used to run the user tests. The prototype should represent the artefact in a synthetic way while avoiding realistic details. In this way, participants will feel encouraged to undertake a creative and participatory attitude (Battarbee and Koskinen, 2005). In this context, we designed an abstract set-up representing the car space, shown in Figure 2. The main goals were to reconstruct the car space around the participant and to physically limit the space of interaction to only that of interest for the study.

Figure 2. Participant in the Abstract Prototype wearing the marker-sets.

The tests were conducted using a Motion Capture system based on 6 Flex 3 cameras by OptiTrack© (Motion Capture Systems, 2014). The cameras were placed at a height of 220 cm, equally distant from each other. The human movements have been tracked using the Rigid Body Tracking modality. This involves capturing only selected parts of the human body, and can be carried out using some wearable devices (Rigid Bodies) covered with retro-reflective markers. Rigid Bodies are defined as clusters of reflective markers in a unique configuration, which allows them to be identified and tracked in a cloud of 3D points. It is possible to track multiple Rigid Bodies at a time in full 6 degrees of freedom (position and orientation, 6DOF). For this case study, we identified 8 areas of the human body to track (head, arms, chest, knees and feet), each of which needed a corresponding wearable marker-sets. The design of these marker-sets had to meet a number of limitations: first of all, they have been designed to fit any user, being adaptive and tight at the same time. Thus, the marker-sets were designed with a soft textile part that would fit any size, and a stiff plastic part fixed with Velcro strips to support a rigid configuration of markers. The shapes of the marker-sets were chosen to maximize tracking capability. Spherical reflective markers were preferred, as they guaranteed the most stable and accurate 3D tracking. Markers were arranged in asymmetrical and unique configurations to reduce the likelihood of misidentification and swapping.

3.2 Tests

The user observations in a real car conducted during the pilot study provided enough information to structure the following tests. Four main problem areas were identified on that basis, namely the research of maximal comfort, the positioning of personal objects, the use of smart devices, and the interaction with the back seats. For this part of the study, we selected 9 participants (5 male, 4 female, aged 25-52). They have been informed of video recording and told about the test goals and objectives. The participants claimed to be at ease with the wearable devices and the researchers could notice that after few minutes of testing, people tended to forget about cameras and markers, focusing on their own experiences. The test was split in two phases: during the first phase participants were asked to recall one meaningful experience as a passenger in the car. This phase relied on the Open Interview technique, according to which people can reveal important issues and opportunities by narrating stories about their daily experiences. Often, what people say and what they actually do is not the same thing. The second phase was instead conducted using a semi-structured approach (Denzin and Lincoln, 2000), by following a set of pre-determined questions to tackle the areas causing problems as defined in the pilot study. Accordingly, the interviewer is allowed to follow new ideas and paths of research that may be brought up during the session. The interviews were video-recorded not only to document participants' feedbacks but also to provide a reference for the subsequent steps of motion data analysis.

3.3 Data analysis & editing

During the tests, we tracked the users' movements and gestures inside the abstract set-up. The goal was to obtain a 3D capture of their movements while simulating and recalling their personal experiences as passenger beside the driver. The expected output is a set of human motion data that constitute a volumetric 3D model representing the (desired) space of interaction for passengers. The data acquired during the tests need to be post-processed in order to be understandable for designers, and to be represented in a way and in an environment that are familiar to them. To reach this result, and to organise the human motion data in an effective visualization, we refined the data through several steps. First, we have cleaned the data from errors and redundancies, and then we have identified the most significant items of information to extract and represent. In this way, the interpretation of human motion data was made more relevant from the designers' point of view. From this information, designers may be able to start shaping new concepts of the passenger seat.

The first step after completing the user tests was to treat data in order to discard any error that has occurred in the system. As mentioned before, the system calibration and the design of the wearable marker-sets may heavily influence the delicate phase of capturing human gestures. Yet, occlusions caused by some movement, parts to be trimmed, misidentification of markers and other accidents can take place. The big amount of data produced during tests (even with a small number of participants) needs then a post-processing phase where data are edited and manually corrected.

The second step was to extract the data from the Motion Capture system, and to make them suitable for a modelling environment. Because of their computational nature, data are difficult to manage for designers, who are more used to use 3D modelling software tools. The large amount of data produced by the Motion Capture system can be extracted as a complex aggregate of information in Comma Separated Value (.csv) format. However, the data sheet produced by the Motion Capture software (Motive©, 2014) is so complex that it must be organised and filtered through some criteria (Figure 3). In this case study, we focused on information concerning the position and orientation of the rigid bodies. Including too many criteria on the same visualization is less desirable, as the difficulty of interpretation can increase significantly. The goal was then to extract only the information about the position of each Rigid Body from the raw data, to create refined data sheets that can be imported in 3D modelling software tools (Figure 3). To automate the process, we implemented a software application that is able to recognise the information associated with each marker-set and generate sub-files listing the (X, Y, Z) position of their centroid for each frame. Subsequently, we were able to import tracking data into a standard NURBS-based modelling software tool. In this way, numeric data are turned into Point Clouds, which represents the first step towards a user-friendly visualization of data. Yet, Point Clouds have still limited possibilities in terms of characterisation. Several variables need instead to be displayed: the number of participants, the different tasks, and the rigid bodies.

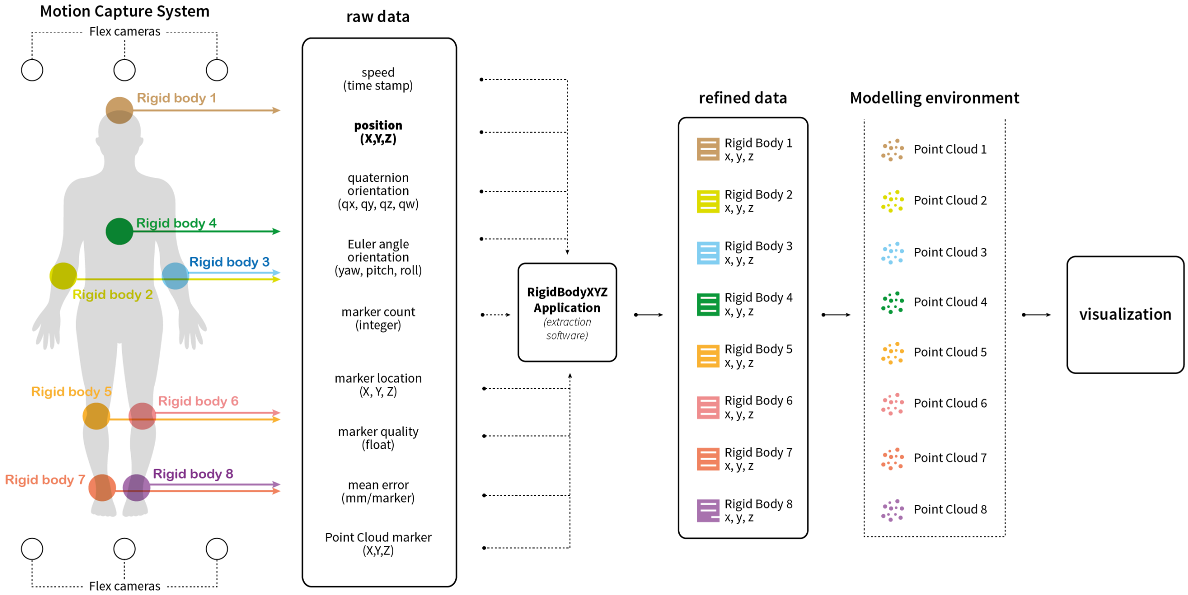

Figure 3. Steps of data refinement.

3.4 Data visualization

The creation of Point Clouds is the standpoint from which motion data can be elaborated in the modelling environment (Figure 3). The next step of the method focuses on how to *make sense* of data, visualizing all the variables that need to be displayed according to the chosen criteria. In this case study, we limited the representation to the position of each Rigid Body over time. Tracking the position and orientation of the Rigid Body associated with the left arm, for example, we are able to trace the trajectory of the arm's movement. Obviously, during the tests users move frequently and they may repeat a movement more than once. In this study, however, the final goal is to represent the volume of the space of interaction, considering not the *quality* of interaction but its *quantity*. Thus, the users' movements are described with a linear representation (a curve) of their trajectories. The overall amount of curves describing every participant's movements defines the limits of the *space of interaction.* To structure the data visualization, we listed the variables to display as the following: (1) motion trajectories; (2) the number of participants; (3) the different tasks; (4) the rigid bodies. We assigned to each variable the following graphical representation reference, respectively: (1) pipes (diameter=2 mm); (2) colours (one for each participant); (3) symbols (4 different symbols, each representing a task) (Figure 4). We decided not to display information about single rigid bodies since it was found highly identifiable even without any specific representation means.

At this stage, the first goal was to generate a spline associated with each Point Cloud. Point Clouds are, in fact, difficult to use as references in the modelling environment, and they lack of representation clarity. After testing several methods, the Bézier curve (degree=11) was found as the most satisfactory spline. Through the Bézier method, the curve is built considering the points in the Cloud as control points, instead of interpolating the spline through those points. Considering the mean error of the system, this method was the most appropriate to achieve a good approximation of the position of the Rigid Body. Yet, due to the high accuracy of the Motion Capture system, these curves required another step of refinement. In fact, the Flex cameras track the Rigid Bodies at up to 100 fps (frame per second). This produces a lot of noise in each acquisition, which can be partially solved already in the Motion Capture system, by performing a track smoothing, and by scaling the accuracy down to 16 fps during data export. However, the curves still appeared redundant in the Modelling environment. A satisfactory result was achieved decreasing the number of control points (10%). The refined curves were used as paths to create pipes. Colours were then assigned to all the pipes belonging to the same participant. Furthermore, the 4 different symbols help identifying each task. Figure 4 shows an example of the graphical representation for one participant. The data are now appropriately visualized and ready to be interpreted by designers.

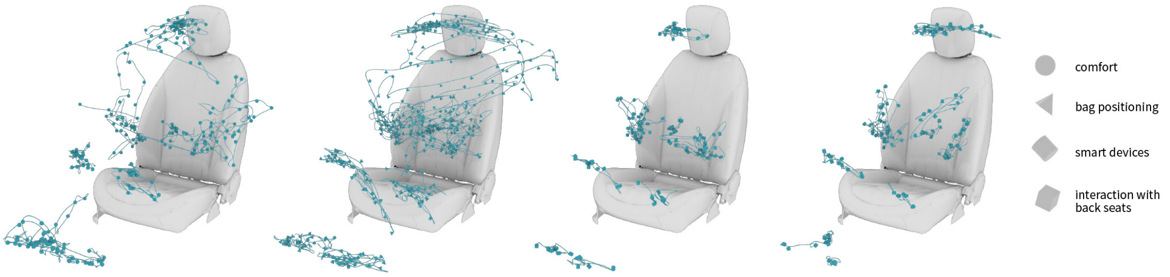

Figure 4. Graphical representation for one participant for each task, respectively: (a) search of comfort; (b) positioning of personal objects; (c) use of smart devices; (d) interaction with back seats.

4 RESULTS & DISCUSSION

The information retrieved from capturing the human body movement needs to be processed in order to support designers. The data visualization reached at this step gives information on the trajectories of the human movements and the areas where users interact the most. This will give the possibility to understand how users interact with the product in some critical focuses, and to specifically design new concepts of the passenger seat as a result. In the method, motion data are coupled with the interview results. These provided other interesting insights, outlining some critical issues for every task. These suggestions reflect the users' movements in the corresponding 3D visualization (Figure 5). The main asset found was the need of an area specifically designed to better integrate the passenger's needs. This involves breaking the symmetry in the car interior design, guaranteeing a larger flexibility in the movements for passengers. The tests highlighted the participants' willingness to interact with the back seats, especially in presence of children, pets and, in general, for long journeys. They showed also to be uncomfortable in their postures, especially with their legs and arms. They claimed to perceive the need of a flexible lumbar support and more space for legs, as well as they would appreciate to have armrests. The complete set of information (3D model of data visualization, renderings, videos and analysis of transcriptions) were organised and transmitted to the design agency. The design team, asked for feedbacks through a questionnaire, asserted that the method was especially significant in the former stages of a project, to inspire and inform designers. The 3D nature of data was specifically found as an interesting standpoint to design the seat *"as a negative shape"*, making the *"form follow the data"*. In this way, *"the design of the style is based on solid, reliable data, merging effectiveness and style"*. Yet, they also suggested some improvements. For instance, they claimed the need for an interface to navigate through the several variables, as well as the integration of other parameters (e.g. *"sudden changes in the users' movements"*; *"the time spent in a certain posture"*; *"the frequency of a specific gesture"*). Moreover, they would largely appreciate the integration of a mobile system for Motion Capture, and the absence (or at least flatness) of markers.

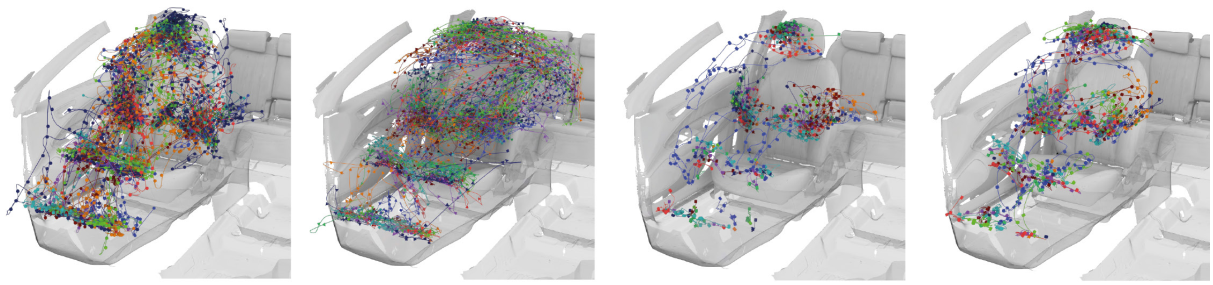

Figure 5. Overall data visualization for each task, respectively: (a) research of comfort; (b) positioning of personal stuff; (c) use of smart devices; (d) interaction with back seats.

The method developed presents some limitations. Firstly, the criteria selected to display motion data are now restricted to the position and frequency only. Yet, a semiotic approach to human movement as the one discussed by Hansen & Morrison (2013) could expand the possibilities, although it would increase the complexity of the data visualization. Moreover, the creation of pipes was considered the most appropriate way to render the motion trajectories and the information on the position of each Rigid Body. Other possible approaches involve the creation of gesture areas, i.e. polygonal meshes generated over the Point Clouds. This process could highlight better the volume of interaction while neglecting the information on the trajectories and orientation (which, in the method presented here, is still inferable from the orientation of the symbols). The integration of 3D human models, as retrieved in Gavrila (1999), offers another possibility of investigation. Nevertheless, the most promising prospect is given by parametric modelling software, so that it will be possible to display and organise a larger number of parameters, e.g. the speed and the orientation.

Compared to traditional user observation methods, such as video recording, this method brings a number of benefits and limitations. Using Motion Capture technologies, human movements can be explored by multiple perspectives instead of the fixed viewpoint of a recording camera. This is a direct consequence of the 3D nature of data, which obviously gives many possibilities to designers. In the modelling environment, movements can be measured and quantified, extracting secondary information as angles, areas, distances, etc. In the analysis of videos, the only possibility is to create snapshots, i.e. static images of a user's movements. Moreover, these representations cannot be overlaid in any way, while human motion data offer the possibility to see the overall volume of users' gestures as a whole. 3D information can have a direct influence on the concept shape: it can be used as the starting point to actually shape the product. Lastly, user anthropometrics can be introduced and compared within a modelling environment, while they are useless with two-dimensional images. As drawbacks, a study employing Motion Capture technique is usually expensive, both in terms of time and resources. One of the research goals was in fact to guide designers and provide enough structure to carry out a similar research in a reasonable time frame. Depending on the specific design problem, however, the focus on users' movements may be less relevant, or the lab environment could influence user perceptions too heavily. In conclusion, we wish to stress the complementary nature of these two types of observation, rather than considering them as exclusive of each other. As the case study demonstrated, a first field research can help planning and organising the Motion Capture session in a more efficient and purposeful way.

5 CONCLUSIONS

This paper presents a new method to make sense of motion data, with the final aim of supplying meaningful insights using a mixed-method approach. Moreover, the research faced the problem of how to refine and visualize the data, providing a systematic procedure to do so. Following the method, we were able to explore the human-product interaction with full 3D information on users' gestures. As this study shows, human movements can be used to infer the users' personal experiences of a space. Motion data can be used to stimulate the concept generation and the shaping of a product. In this study, we presented a case study in the automotive sector. The efficacy of the method could be validated through other case studies, with other kinds of products. All the products involving a spatial interaction seem more suitable to the topic, as for those the study of human gestures acquires more value. More specifically, examples are the design of home/office stationeries or computer interfaces (similar to face tracking standard case studies). The healthcare provides even more possibilities, as well as other transportation means (trains or airplanes). Lastly, many sports can be an interesting source of case studies. While the visualization of motion data has been sufficiently addressed by this study, the designers' viewpoint should be further investigated, to understand how designers could exploit this kind of data. Strategies to support this moment should be implemented, as, for example, an interface to navigate through the several variables. Finally, it would be beneficial to clearly assess the costs in terms of time and resources that this method implies. It is important to point out that with well-defined guidelines, such as the ones provided, the levy of the method is significantly reduced.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of FCA Group and Design Innovation. We wish to thank Giorgio Masoero (CRF), Filippo Lorini and Mark Salerno (Design Innovation) for their precious technical and methodological support to develop the case study. We also express our gratitude to Matteo Troiani for his contribution in processing the Motion Capture raw data.

REFERENCES

Battarbee, K. and Koskinen, I. (2005) Co-experience: user experience as interaction. CoDesign, 1(1), 5-18.

Bordegoni, M. and Caruso, G. (2012) Mixed reality distributed platform for collaborative design review of automotive interiors. Virtual and Physical Prototyping, Vol. 7 No.4, pp. 243–259.

Chaffin, D.B. (2002) On simulating human reach motions for ergonomics analyses. Human Factors and Ergonomics in Manufacturing, Vol.12 No.3, pp. 235–247.

Du, J., Duffy, V.G. (2007) A methodology for assessing industrial workstations using optical motion capture integrated with digital human models. Occupational Ergonomics. Vol. 7 No.1, pp. 11–25.

Creswell, J.W. (2003). Research design: Qualitative, quantitative, and mixed approaches. Thousand Oaks, CA: Sage.

Denzin, N. K. and Lincoln, Y. S. (2000). The discipline and practice of qualitative research. Handbook of qualitative research, 2, 1-28.

Desmet, P. M. (2002) Designing emotion. Unpublished PhD thesis. TU Delft.

Dorst, K. (2011) The core of design thinking and its application. Design Studies, Vol. 32, No.6, pp. 521-532.

ENGAGE, (2006) Report on the evaluation of generative tools and methods for ‘emotional design’. Deliverable D15.3. EU project Engage 520998.

Forlizzi, J. and Battarbee, K. (2004) Understanding experience in interactive systems. Designing Interactive Systems, Cambridge (MA), 1-4 August. New York: ACM, pp. 261-288.

Gatti, E., Bordegoni, M. and Camere, S. (2014) Experiences and Senses. An Experimental-based methodology to support design optimization. 9th International Conference on Design & Emotion, Bogotà, 6-8 October. Bogotà: Ediciones Uniandes, pp. 340-388.

Gaver, B., Dunne, T. and Pacenti, E. (1999) Design: cultural probes, Interactions, Vol.6, No.1, pp. 21-29.

Gavrila, D. M. (1999) The visual analysis of human movement: A survey. Computer vision and image understanding, Vol.73 No.1, pp. 82-98.

GoPro Official Website (2014) http://it.gopro.com/ [accessed 24/11/2014].

Graziosi, S., Ferrise, F., Bordegoni, M. and Ozbey, O. (2013) A method for capturing and translating qualitative user experience into design specifications: the haptic feedback of appliance interfaces. International Conference on Engineering Design, Seoul, 19-22 August. Seoul: The Design Society, pp. 427-436.

Hansen, L. A. and Morrison, A. (2013) Materializing movement. Designing for movement-based digital interaction. International Journal of Design, Vol.8, No.1, pp. 29-42.

Hassenzahl, M. (2010) Experience design: Technology for all the right reasons, San Francisco: Morgan & Claypool.

IDEO (2008) Human Centered Design Toolkit, [online], available: http://www.hcdconnect.org [accessed 24/11/2014].

Isomursu, M. (2008) User experience evaluation with experimental pilots, In: Väänänen-Vainio-Mattila, K.; Roto, V.; Hassenzahl, M. (2008) Now Let’s Do It in Practice: User Experience Evaluation Methods in Product Development, Workshop at CHI2008.

Kinect for Windows (2014) http://www.microsoft.com/en-us/kinectforwindows/ [accessed 30/11/2014].

Laurans, G. (2011) On the Moment-to-moment Measurement of Emotion During Person-product Interaction. Unpublished PhD thesis. TU Delft.

Maguire, M. (2001) Methods to support human-centred design. International Journal of Human-Computer Studies, Vol.55, No.4, pp. 587-634.

Mengoni, M., Peruzzini, M., Mandorli, F., Bordegoni, M. and Caruso, G. (2008) Performing Ergonomic Analysis in Virtual Environments: A Structured Protocol to Assess Humans Interaction. In Volume 3: 28th Computers and Information in Engineering Conference, Parts A and B. New York: ASME, pp.1461–1472.

Merleau-Ponty, M. (1962) Phenomenology of Perception, London: Routledge & Kegan Paul.

Motion Capture Systems (2014) http://www.naturalpoint.com/optitrack/ [accessed 30/11/2014].

Motive (2014) https://www.naturalpoint.com/optitrack/products/motive/ [accessed 30/11/2014].

Perret, R. (2010) Bodycloud, Unpublished work. http://raphaelperret.ch/bodycloud/ [accessed 24/11/2014].

Tullis, T. and Albert W. (2008) Measuring the user experience: collecting, analyzing, and presenting usability metrics, San Francisco: Kaufmann.

Vermeeren, A. P., Law, E. L.-C., Roto, V., Obrist, M., Hoonhout, J. and Väänänen-Vainio-Mattila, K. (2010) User experience evaluation methods: current state and development needs. Nordic Conference on Human-Computer Interaction, Extending Boundaries. New York: ACM, pp. 521-530.

Visser, F. S., Stappers, P. J., Van der Lugt, R. and Sanders, E. B. (2005) Contextmapping: experiences from practice, CoDesign, Vol.1, No.2, pp. 119-149.

Vroman, L., Naveda, L., Leman, M. and Thierry, L. (2012) Generating tacit knowledge through motion: A vision on the matter of space. Art, Design & Communication in Higher Education, Vol.10, No.2, pp. 255-270.