Analysis of the integration of a Spatial Augmented Reality platform in a context of collaborative design involving end-users.

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Analyse de l'intégration d'une plate-forme de réalité augmentée spatiale dans un contexte de conception collaborative impliquant des utilisateurs finaux

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You were my voice when I couldn't speak

You were my eyes when I couldn't see

You saw the best there was in me

Lifted me up when I couldn't reach

You gave me faith cause you believed

I'm everything I am Because you loved me."

Thanks Almighty!

Fatma,

ANALYSE DE L'INTEGRATION D'UNE PLATE-FORME DE REALITE AUGMENTEE SPATIALE DANS UN CONTEXTE DE CONCEPTION COLLABORATIVE IMPLIQUANT DES UTILISATEURS FINAUX

ANALYSIS OF THE INTEGRATION OF A SPATIAL AUGMENTED REALITY PLATFORM IN A CONTEXT OF COLLABORATIVE DESIGN INVOLVING END-USERS

Fatma Ben Guefrech

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MATRICES

LIST OF ABBREVIATIONS

AR: Augmented Reality

CSCW: Computer Supported Collaborative Work

ICT: Information Communication Technology

IO: Intermediary object

IS: Information System

MR: Mixed Reality

PD: Participatory Design

SAR: Spatial Augmented Reality

SBD: Scenario Based Design

UCD: User Centred Design

VR: Virtual Reality

GENERAL INTRODUCTION

Creative design activities and products are more and more ubiquitous in our society today. Our daily environment includes a multitude of objects that have previously been designed. The design of complex industrial products takes place in extremely varied professional fields and requires collaboration of multiple actors ranging from highly technical sectors to artistic sectors throughout the design process. We note that exchanging ideas and coordination of work requires a high degree of collaborative interaction under diverse forms: meeting, presentation, report, brainstorming, etc.. Regardless of the areas considered, designers need to develop products that are both innovative, user-friendly and appealing (Bonnardel, 2009).

Design organisations are facing important changes driven by an extremely aggressive market competition; they are constantly adding new features to their products that requires more and more the collaboration of a growing number of diverse actors with different types of expertise. This increasing the complexity of the design process amplifies the importance of communication in the success of their projects. In order to improve the results with regard to the quality, cost, time and the globalisation of markets, designers need to work in a collaborative environment in order to create a shared understanding between the different actors involved in design team.

On the other hand, the communication in multidisciplinary teams is critical. There is a constant need to adapt means of communication. One of the favourite designers' communication artefacts is the prototype and the 3D digital mock-up. Today, among cooperative artefacts, three-dimensional product representations are increasingly being used as communication media, since they provide a common understanding of design solutions to actors in different fields with limited time and cost of production.

In addition, market competition is also driving companies to follow global strategies. The most recently used trend in industry is to involve end-users within the design process. Design approaches such as user-centred design and co-design take new forms and involve new actors as effective partner of design activities (E. B. N. Sanders & Stappers, 2014). The business Innovation Observatory states that involving non-designers to the design task present business benefit such as increased speed to market and reduced risk of market failure by avoiding innovation suggestions not meeting customer needs(Innovation Observatory Business, 2014). Therefore, designers need to discover, understand and exchange ideas and suggestions with end-users in order to be able to transform their needs and requirements into adequate technical solutions and eventually turned it into proper products. However, the involvement of external stakeholders can imply difficulties due to communication barriers and the difference of backgrounds leading to different understanding of the design process.

To overcome these communication difficulties, and considering that in design activity, it is essential to be able to represent ideas with a suitable tool, new technologies allow envisaging new tools allowing different types of product representations to exist and in particular displaying shape and appearance. 3D modelling of a physical object allows for example its visualisation on a screen, or in a virtual reality headset. This technology for representing the objects is both closer to the real world than 2-dimensional representations on paper, and saves time and cost compared to physical prototyping or modelling.

This last point can however be seen as a disadvantage since these digital technologies do not allow the manipulation of the object, which can however be interesting for the generation as for the transmission of ideas throughout the design process.

Consequently, interaction with three-dimensional objects has become a prominent feature in recent years. Indeed, the technological progress makes it possible today to display very high quality rendering on complex objects' geometry. This development then induced a large need for manipulation of these objects. Unfortunately, few commercial solutions provide good support for collaborative interaction with 3D elements.

Augmented Reality (AR) is perhaps the best candidate technology that could properly address these problems. As it allows integrating virtual objects in our real environment, this technology allows to manipulate them more naturally. Based on this concept, a user can maintain his usual collaborative environment and integrate 3D interaction possibilities. The use of a physical space to communicate ensures a conservation of natural connectivity: in Virtual Reality (VR), it is necessary to reproduce the environment and the avatars of the participants. Numerous studies carried out in VR have shown limitation in this "virtualisation" of the natural metaphors of communication. The solutions are limited and are still far from true arguments(Guye-Vuillème, Capin, Pandzic, Magnenat Thalmann, & Thalmann, 1999). The Augmented Reality preserves the natural metaphors, and enhance them with various properties such as combining the display possibilities of VR with the possibility of manipulating and interacting with physical objects.

Spatial Augmented Reality technology (SAR) differentiates itself from other augmented reality technologies by directly using objects or physical scenes to display the desired information using projection mapping. The SAR technology does not require head mounted displays, which are typically associated with a single user virtual reality. Therefore, SAR allows multiple users to collaborate directly in a physical scene(Ippolito & Cigola, 2016), and not be isolated in a reconstructed virtual scene. Some authors have already worked on different tools using SAR, such as(Akaoka, Ginn, & Vertegaal, 2010) and (Verlinden, 2014) and state that SAR technology “enriches” physical models with features, materials, and behaviour. They test their tools in various design situations, and observe a certain attractiveness of the users, despite some uncomfortable aspects, such as the fact that the hands may hide a part of the projected image, that the tracking of the fingers of the users is still too inefficient to have good user interaction with the system.

The study of (Ippolito & Cigola, 2016) highlights that SAR is potentially an interesting tool for collaborative design. Co-design involves including the end user in certain stages of product design process. According to(Cristol, 2018), this method brings a shift in point of view, methods and professional practices that contributes in rethinking forms of objects, but also about human interactions. Among the advantages of co-design cited in the study of (Prahalad & Ramaswamy, 2002), in particular, the increase of users' knowledge on various subjects related to the design company, which can enable them to bring an external but interesting opinion. This study relies on a unique attempt to develop a full SAR environment dedicated to support designers in the development of co-design sessions. This potentially will address to major issues presented before: the difficulty of integrating end-users while ensuring a cost limited impact on the prototyping phase. The new practices based on an SAR environment therefore seemed to us an interesting aspect to study. The European project SPARK aimed to propose a new tool for these representations, which reduces the number of prototypes to be made, while allowing a physical interaction with tangible objects. This tool is a Spatial Augmented Reality (SAR) platform, which requires a number of technical modules to allow design sessions to take place.

In this context, incorporating the virtual into the real world can induce a certain number of questions: “How to manage the real / virtual combination in a collaborative setting?” “Does the integration of mixed (physical/digital) design artefacts can be an added value to interaction between design participants?”

An important point that SPARK platform, our research proposed tool, wanted to consider is the ability to support this collaborative design work. The adapted choice of SAR is therefore supported by the fact that this technology does not restrict the ordinary communication channels such as gestural and verbal communication of the users. Indeed, SAR do not require additional equipment to be used by the participant and allows tactile feedback to the user, since he manipulates a physical object. In addition, the developed system offers an interface that is intended to be relatively intuitive, so end-users can easily and quickly get familiar with it. The objective of this thesis is to analysis to what extent the SAR artefacts can improve communication and if communication is not impaired by this new type of interaction. The main aim of the SPARK project was to reduce the ambiguity of information transfer in design sessions based on the use of mixed tangible-digital representations. In this thesis, we evaluate the capability of this technology to enhance the involvement of external stakeholders in collaborative design process.

One important challenge addressed during this thesis was to evaluate the impact of integration of a spatial augmented reality platform in collaborative design meetings. We wanted to demonstrate that the SPARK platform, through the introduction of new prototype mixing the tangible aspect with digital projection, positively impacts the co-creative design sessions and the overall communication interactions between the different stakeholders.

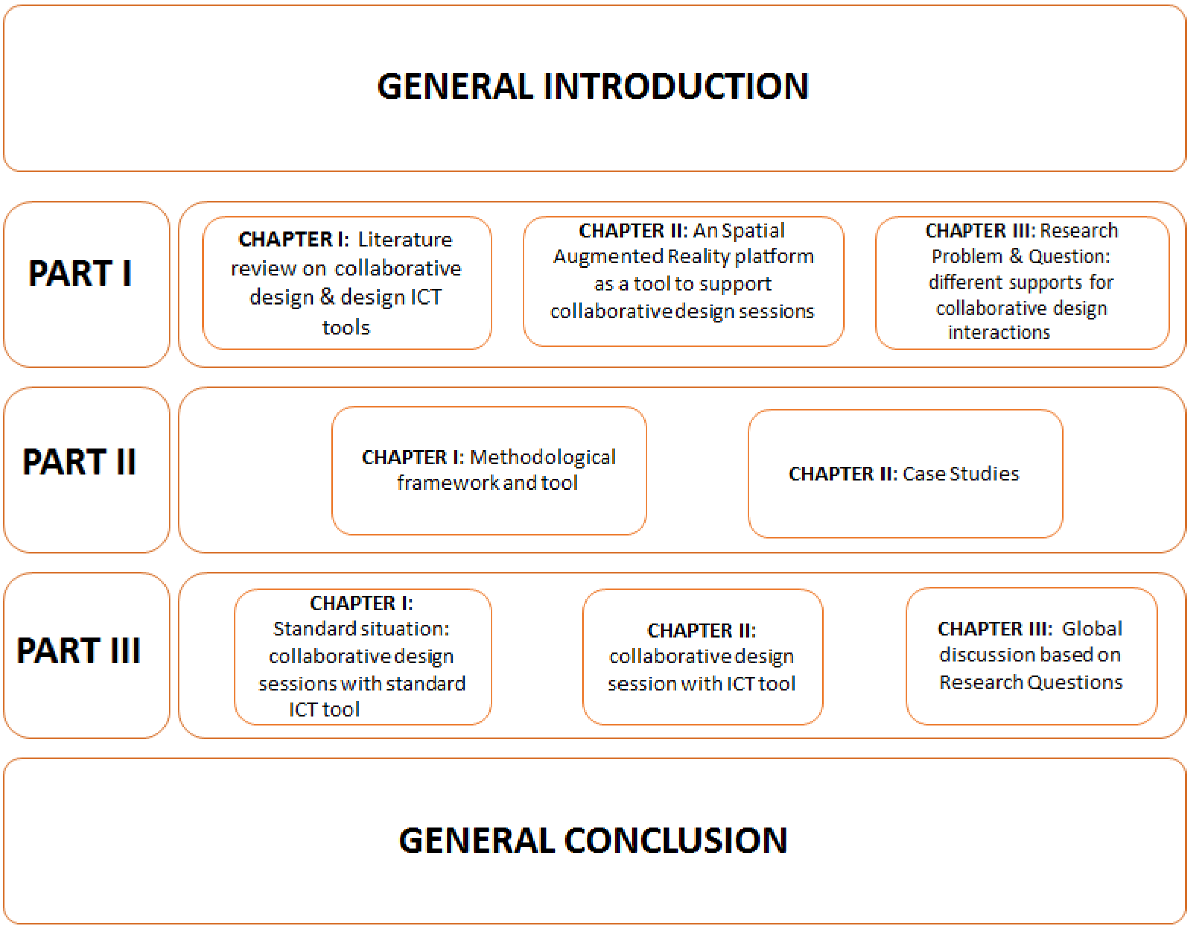
The overall aim was to investigate and analyse the dynamics of the collaborative design interactions through a typical set of case studies involving industrial participation, which characterises the conventional way of work (i.e. standard situations) and then with a second set of sessions involving the SAR technology. Within this activity, we observe collaborative meetings between our SPARK industrial partners and their clients at their own premises. In addition, we reproduced the same design environment in our lab in order to invite our partners to a set of controlled observations with recruited end-users.

This thesis is organised in three parts after this introduction. The first part describes the theoretical context of our work. It presents a state of the art on collaborative design and the ICT tools used to support it and the various user-centred approaches including the external stakeholders in the design process. We then present our research context and propose the research questions. The last chapter details the SPARK platform as a tool to support collaborative design meetings.

The second part considers the research approach and presents mainly the methodological framework and the development procedure used in our data analysis. The last chapter presents in detail the cases studies involving our industrial partner with their clients and end-users. We will introduce here our research questions.

The third and last part is dedicated to the analysis of the case studies in both conditions: conventional sessions and collaborative sessions supported by different ICT technologies. We analyse the role of artefacts in the different conditions, the interaction modalities involved by participants. Then for each session, we evaluate the involvement of external stakeholders and to what extent the mixed artefacts can enhance their participation. A last chapter discusses the findings based on the research questions presented in the second part.

Finally, the conclusion summarises the contributions of this thesis, by recalling the various aspects of the collaborative design process that we have been interested in, and by listing the associated findings considering the mixed artefacts in involving end-users and enhancing communication within collaborative design participants, as well as the elements that remain to be validated or developed.



PART I LITERATURE REVIEW ON COLLABORATIVE DESIGN & CONTEXT OF RESEARCH

Abstract

In Part I we set the state of the art of existing research studies concerned with collaborative design approach and present our research work context and questions.

The first chapter, based on literature studies, allows us to discuss definitions of the design process in general. Then, we define product design process and collaborative design process in an industrial context. It allows us to define the design process as a collective and collaborative process involving technical and social knowledge. We study well-known approaches considering users in the design process, example includes User centred design, Participatory design and Scenario Based design. These concepts bring a deep understanding and of users' needs integration. As well, we study the technical aspects of collaborative design from the ICT tools point of view. We hypothesis our arguments considering that Spatial Augmented Reality is a suitable tool to support collaboration in design.

The second chapter presents the ICT research tool, which is a Spatial Augmented Reality platform, developed within the SPARK H2020 project and that will be the core technological element used in this thesis. In addition to the assumption of this project that SAR technology can foster collaboration and enhance users' participation, we present the physical structure of the platform and its different software components. We then, provide an example of how a collaborative design session can be supported by the SPARK platform.

The last chapter is dedicated to present the research problem and questions addressed in the thesis. We establish a state of the art around the different supports for collaborative design interactions and we give a special focus on the role artefacts play in this field. Then, we introduce our research problem that focuses on the communicative role that artefacts play in collaborative design interactions. Based on previous research studies we formulate our research questions spotting the role of Spatial Augmented Reality artefact in collaborative design interactions and its impact on end-users enhancement in the collaborative design activity. Finally, we suggest a controlled study to investigate the research question. The results of this study aims at highlighting the role of Spatial Augmented reality artefacts play in communication and as a support for collaborative design interactions.

CHAPTER I: Literature review on collaborative design & design ICT tools

Abstract

The literature review of our research study was built around the definitions of principal concepts that structure our area of interest. We first tend to investigate the existing studies on collaborative design field. Then, we explore the existing ICT tools to support these specific type of design meetings.

We start by defining the concept of design process, its important steps and the actors involved. Then, we focus on product design process, as it will be our research application area. We investigate the social and technical dimensions of the design process and more particularly its collaborative aspects..

We underline the misunderstandings and problems that may occur in collaborative design sessions especially when involving external stakeholders. We present different types of difficulties faced by end-users while participating in design task. Since we are interested in the involvement of stakeholders, we structure our literature based on the well-known approaches considering users in design process such as User centred design, Participatory design and Scenario Based design. They suggest methods for a better understanding and integration of users' needs.

As we define collaborative design an approach requiring methods and tools to support the rich interactions between the different involved actors. We dedicate the last part to present multiple digital tools to support the design activity. Based on literature, we cite the characteristics of an ideal tool that could ensure an efficient communication. Then, based on these criteria, we test the eligibility of several technologies such Virtual Reality, Augmented Reality and Spatial Augmented Reality. The Spatial Augmented Reality features and characteristics seem to be a suitable technology to support the exchanges in collaborative design context.

1. Collaborative Design process

1. Definitions of the Design process:

Several research studies consider design as a series of sequences articulated along a process that is defined as the design process (Rasoulifar, 2009). This design process can be performed in different ways. According to the study of (Hubka & Eder, 1995) there are intuitive ways to perform design process and more structured methods. One of the simplest but well known model to structure the design process is the one proposed by Cross(Cross, 1998). The model describes the basic activities involved in the design process as shown in Figure 1:

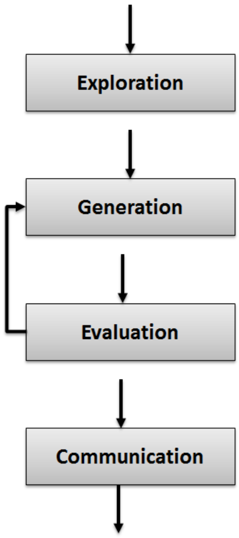


Figure 1. Simple four-stage model of the design process(Cross, 1998)

The model presents the basic activities that can be performed by a designer. It highlights that during this process, designers do not convey directly to a discussion on a final proposal but go through a number of loops between idea generation and evaluation of proposals.

Similarly, there are several more sophisticated and complex models to represent the design process such as the model proposed by (Pahl, Beitz, Feldhusen, & Grote, 2007). They divide the design process in a sequence of steps: Planning, Concept Development, System-Level Design, Detail Design, Testing & Refinement and Production & operation. In each of these steps, they specify the list of sub-tasks to be executed by the company for each product development.

These descriptive models of the design process stress the importance of the iterative feedback loop between the generation phase and the evaluation stage. They assume that the designers do not go straight to a direct solution because of missing functionalities or unsatisfied needs, which perhaps come from a very superficial definition of the problem. Therefore, the study of (French, 1985) illustrated in Figure 2 states that designers should start with the definition of the problem as a statement of a need. As a first step, the designer must perform a deep analysis of the needs. Then analyse it by defining the design goal, the limitation of the potential solution but most important the criteria that the design should approve.

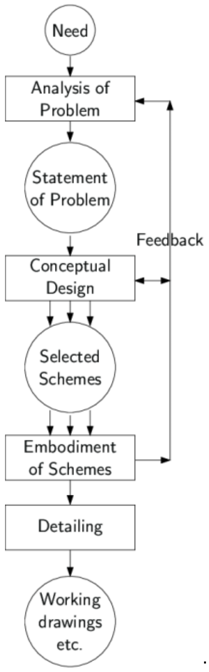


Figure 2.Design process model(French, 1985)

As proposed in the model of Cross (Figure 1), the evaluation step is where design team compare the predefined proprieties and needs established in analysis phase to the expected value of the proposal. The last step of communication is the decision-taking phase where design team evaluate the proposal and decide whether it is acceptable or not. Then based on this decision, the process can be finished or rejected and the team go back to the statement or even to the analysis step.

We can also cite the Double Diamond Model proposed by the Design Council. As presented below in figure 3, the model spots clearly that the design process adopts divergent thinking from the beginning. This model shows the two different approaches to problem solving. It highlights the contrast between divergent thinking and convergent thinking.

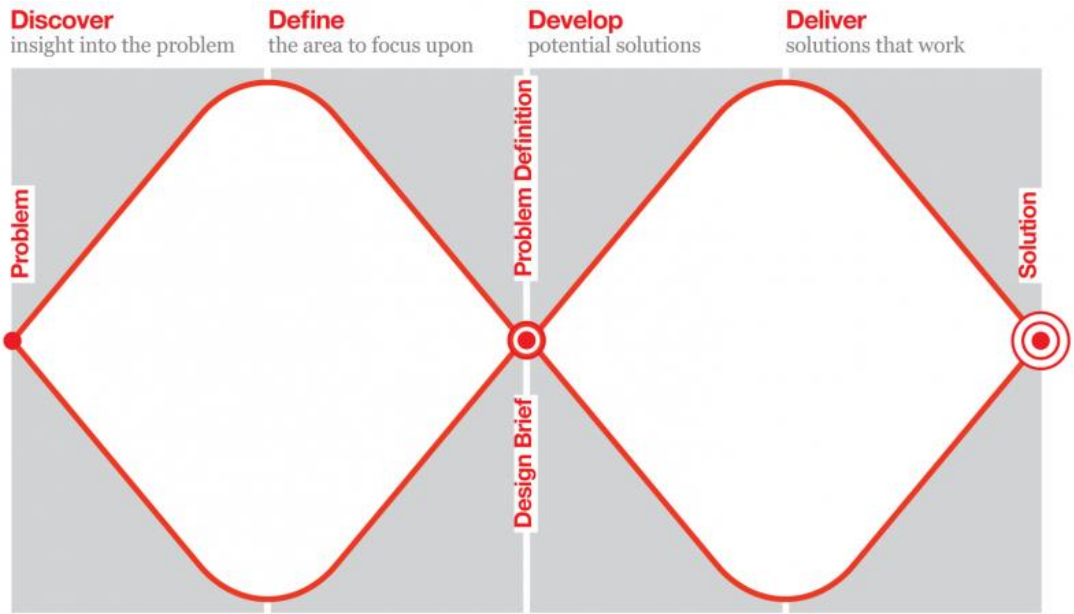


Figure 3. The Double Diamond Model by the Design Council

This model is structured into 4 phases: discover, define, develop and deliver, all in an iterative way. It offers two phases: divergent phases enclosing open and explore possible ideas and convergent phases, in which design participants reduce and refine the best ideas.

2. Social dimension of Product design process and intermediary objects

The design process of a product is defined by Engwall and al. as a collective and collaborative activity (Engwall, Forslin, Kaulio, Norell, & Ritzén, 2003). Thanks to this collective aspect, designers charged by different tasks can coordinate their activities and exchange information between each other and with other teams involved in the product development process. Accordingly, the study of Bucciarelli(Bucciarelli, 1994) considers the design as a social process and confirms that the design task is not a privative space of any individual to set or describe and define by himself. He states that even though design participants have their own views, thoughts, sketches, diagrams and personal opinion on the product design, the latter still a common and shared space. This is the case for many other studies, such as the book of (Mcdonnell & Lloyd, 2010) and the study of (Lloyd, 2000) which perceive the design process as a socio-technical activity but within the engineering design organisation the authors consider it in its social dimension.

This social process involves communication between different actors. Communication can cause problems between participants who have potential different profiles and backgrounds. This approach implies considering different mental representations and understanding of design and design problem. Star (Star, 1989) studies the role of boundary objects as communication channel between participants who have different skills and disciplines. Moreover, the study of Vinck and Jeantet (Vinck & Jeantet, 1995) propose the notion of intermediary objects. The author considers the intermediary objects as mediators representing the future product. Therefore, the analysis of these communication channels can allow a deep understanding on how the product is designed, but also how it is influenced by these objects (J.-F. Boujut & Blanco, 2003). (Claudia M. Eckert & Boujut, 2003) states that the design process is influenced by these representations and consider the objects as a vector of expression of design constraints and technical knowledge.

According to these studies, we understand the product design as a social and technical process. The designers start with defining what a product needs to fulfil and finish when they find the models and representations that define the product. In addition, the design process covers the aspects related to the collaboration between different design actors as well as intermediary objects which are considered as communication instruments, expressing ideas tools and representations of future product.

3. Collaborative design process

The design of complex products requires the intervention of several actors with different skills, who collaborate. Therefore, the design process regroup various domains of expertise (Longchamp, 2003). The need for collaboration is required when individuals do not have the capacity to carry out a given task alone. Through collaboration, the designer can solve problems that are more complex: group members help him, he learns from others and the situation motivates him.

Different definitions of collaboration are proposed: In their studies (Jacobs, Sokol, & Ohlsson, 2002) define collaboration as an activity performed by multiple people to achieve shared goals. This is why it requires a common language and experience, and a shared environment and media (tools). (Scharge, 1990) proposes a definition "collaboration is an intentional relationship created for the purpose of solving problem, creating or discovering something in a situation subject to a set of constraints". Based on (Kak & Schoonmaker, 2002) study, they define collaboration as “*any process by which two or more separate authority domains coordinate their decisions, resulting in plans that are superior to the plans they would have likely made without coordinating their decisions*”. They consider that coordination of decisions is the essence of collaboration. According to these definitions, we can consider collaboration as a process requiring shared objectives by different members of multidisciplinary teams. Through social interactions, members integrate their knowledge, that is, learn from each other to achieve a common goal through their own tasks.

Considering the previous definition of collaboration, we can define the collaboration in design process. According to Blessing (L. T. M. Blessing, 1995) the collaborative design is a complex activity involving actors, artefacts, tools, organisation and context. Thus, it is an activity integrating social, technical and organisational aspects, involving actors, tools, and instruments to perform predefined tasks.

In the context of industrial enterprises, the study of Wang and al. (Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002) states that collaborative design can be observed in a wide variety of situations throughout the product life cycle: development, design, manufacturing, assembly, testing, quality, purchasing, relationships with customers and suppliers.

Collaboration is a complex activity that implies a double complexity: an external one due to the customers and their needs associated to an internal one due the designers with their different specialities, or the technical strategy of the company(J. F. Boujut & Tiger, 2002). Therefore, the objectives of collaborative design teams are to achieve collective agreement in order to optimise the functions, to minimise the costs and to ensure the sustainability of the product(Koufteros, Vonderembse, & Doll, 2001).

The study of collaborative situations has been developed in different fields. Several collaborative models emerged from these studies. For example, following a study in the field of architectural design, (Kvan, 2000)proposes a design collaboration model presented in Figure 4.

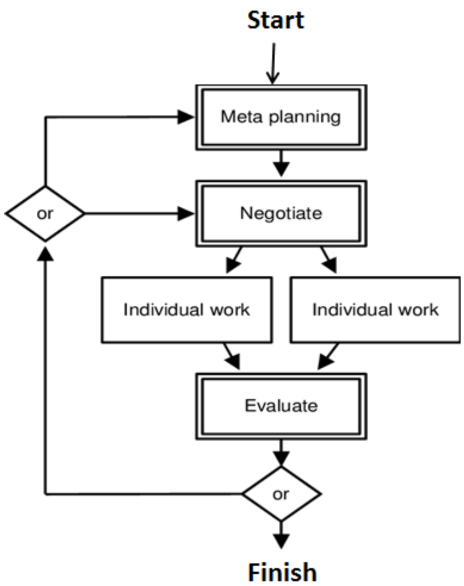


Figure 4. A model of design collaboration(Kvan, 2000)

The author claims that collaborative design consists of parallel actions of experts. Each of these actions is short-term, and they are framed by common negotiation and evaluation activities. Therefore, the design activity itself is discrete, individual and parallel, not necessarily linked. Designers act as experts considering design aspects of their perspectives. The expertise of these actors can evolve during a design session thanks to their mutual understanding and learning. However, Kvan's approach is considered a coordination approach of activities and there is no collective activity between design participants. Thus, contradictory to the above presented approaches that focus on the collaborative aspects between design participants. Our research context is focused on how to enhance the collaborative aspect between design actors. Therefore, the design models that suits us are the ones related to the collaboration aspect.

(Chiu, 2002) proposes a collaborative design model based on decision-making (Figure 5). Design information is provided from the initial phase to the final phase until the decision-making process is complete. Therefore, the cycle of information flow involves consultation, negotiation, decision-making and ultimately reflection.

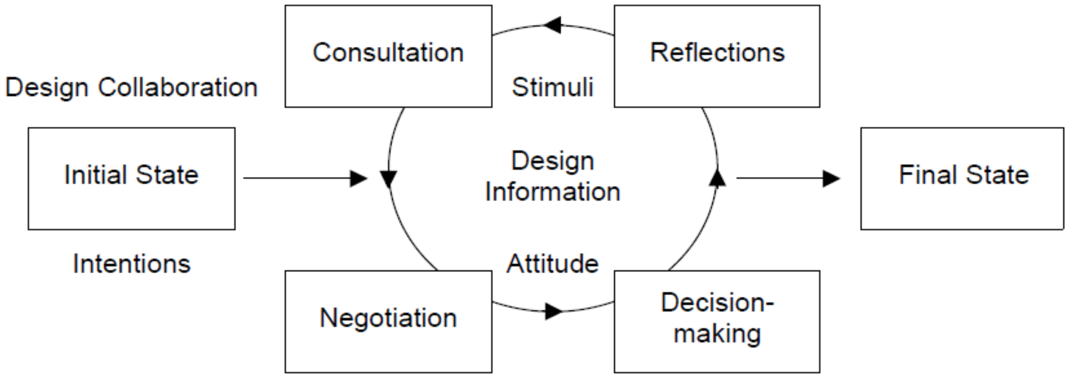


Figure 5. A process model of design collaboration(Chiu, 2002)

According to Chiu, negotiation is considered as an important task of decision-making in collaborative design. Consultation is a verification activity of decisions to be made. The purpose of the reflection is to confirm the result of the decision-making and to initiate another cycle in the processing of the information. In the process, the stimulus and attitude of participants are also critical to decision-making. The author suggests the proposed model as a help to understand how design collaboration can speed up the process through efficient organisation as well as communication through possible computer-assisted systems.

(Chartier, 2007) defines the characteristics of the collaborative design: It must allow effective communication between group members; facilitate mutual aid between design actors and reducing ambiguity. A collaborative design process is based on a good division of responsibilities and take advantages of knowledge and experiences of each member in order to achieve a common goal. It also involves a good coordination of tasks and ensure the same level of shared ideas between members.

Finally, collaborative design is a collective activity of open problem solving. It is characterised by social, technical and organisational dimensions. As a technical and scientific activity, it requires knowledge, models, methods and tools.

The human dimension of design implies taking into account the cognitive and social processes, including questions about individual and collective knowledge, skills, roles and logic(Darses, 2002). The following paragraph discusses potential problems that design team may face when involving internal and external stakeholders in the design process.

2. User participation in the design process

In recent decades, design processes have changed dramatically. The cited research studies demonstrate that design organisation has moved from a sequential structure to an integrated structure to meet customers' needs and reduce time to market. This evolution implies finding organisations to work in short time, with limited budgets and an improvement in the complexity of the product. Ulrich & Eppinger underline that the product must meet the requirements and needs of the customer (Ulrich & Eppinger, 2000). The sequential organisation of design process has therefore push to change the structures and give more flexibility through the integration of stakeholders in preliminary stages of product development. Therefore, Involving stakeholders enables companies to effectively make better informed decisions, thereby reducing lead times and preventing costly last-minute changes(Ruiz-dominguez, 2008). The study of Salinas and al. says that the design process is a sequence of activities with a purpose of satisfying the clients' needs(Salinas, Prudhomme, & Brissaud, 2008). The same study distinguishes two types of "client": The first client category is the client to whom the product is developed for. This stakeholder generally does not belong to the design company. The authors called him 'external client'. The second category of client is the experts concerned with life-cycle product. They are called 'internal clients' and generally they belong to the company. They bring professional expertise and considerable industrial viewpoints on the product lifecycle. Instead of need, internal client express their opinions as product or process constraints. The essence of the collaborative design process is bringing these different categories of clients to designers' expertise. Their different feedbacks whether are needs or constraints should be considered and integrated in order to have efficient design process. The confrontation of the points of view of the different actors is thus inevitable. It is even desirable to design a better product. However, this confrontation may bring some problem when we involve users in the design process: we are wondering if design team members understand exactly the communicated information? To what extent designers understand and identify correctly the user's needs? The next two paragraphs present the eventual problems that can be faced by the design team.

1. Problem of mutual understanding between design actors

According to the cited bibliography, involving different stakeholders in the design process have an added value. However, the review of (Kleinsmann, Valkenburg, & Buijs, 2007) comes up to highlight potential problems where collaborative design process involve different actors with different backgrounds and skills. Their empirical study of collaborative design projects in industry investigates which factors influence the creation of shared understanding causing problems in multidisciplinary design teams. According to Kleinsmann and al. there are four factors related to the actors and affecting the creation of shared understanding:

- How actors make transformation of knowledge. Since they are coming from different disciplines and then using different knowledge, they need to transform the content and the representation of the knowledge.
- An important issue is related to the use of different native language and technical jargon.
- Actors are influenced by their earlier experiences while designing. Design team rely on the experience of external actors to gather information about the innovative aspects in the design project. However, these external actors have a lack of experience in specific aspects of the design, thus can create problem of shared understanding.
- Actors' personal implication and interest in a design task: The empathy of actors to fulfil a task or to communicate with other team members about a task.

As mentioned above, communication between design actors is crucial to avoid the problem of misunderstanding. Some research studies such as Clark and al(Clark, Herbert H., Brennan, 1991) consider that building a common ground improve the effectiveness of the communication. The grounding activity helps design actors to co-create the shared representation of the current situation of the problem and move a step ahead to solutions. The design team have several medium to accomplish the communication task; the most basic is speech. According to Dong (Dong, 2005) generating a common language-based communication can significantly improve knowledge construction within the team. They have to make sure that what have been said is what exactly have been understood.

As we cited before, the confrontation between design actors is probably inevitable. Disagreements within a design team can have positive impact. De Dreu assumes that having confrontations can push design team to perform deeper analysis and thus increase task creativity(De Dreu & Weingart, 2003). However, these divergences of opinion can affect the progress of design task. It cannot be solved by direct confrontation they must be resolved otherwise. Design team members can reach opinions' convergence through negotiations. Negotiation is stressed as an important step of the design process, designers argument their choices and explain their constraints in front of some users' needs or wishes.

2. Problem of understanding users' needs

Involving users in the lifecycle of design process is the trend for design companies. They look for a better understanding of the users' needs. They also aim to optimise their products and minimise the market risk. In the literature, the suggested solution is to develop the dialogue between designers and users. According to (Niès & Pelayo, 2010) the direct exchange between designers of products and users is not sufficient to ensure a proper understanding of the users' needs. The study suggests the involvement of human factors specialists to analyse the users' expression of their needs so the requirements of design will be then properly formalised. The same idea is shared in the study of (Saiedian & Dale, 2000) which links between a product that meets the original needs of the users and an efficient support that facilitate the user-designer communication. Multiple communication difficulties are raised between users and design actors. The most basic one is that design actors do not have predefined common languages. Stakeholders and designers do not have same level of technological skills; the jargon used by designers might be incomprehensible for users(Erickson, 1995).

On the other hand, Niès and Pelayo report that collaborative work between experts and helps resolve the limits of direct users involvement and usual problems pertaining to users' needs description and understanding(Niès & Pelayo, 2010). The diverse limits cited above, have been treated from different point of view through multiple approaches described hereafter. The following paragraph answers the problems we raised in this section.

3. Approaches considering the user in product design process

Smith and Smith assume that the success of a product is strongly related to the satisfaction of the consumer needs(Smith & Smith, 2012). (Mantelet, 2006)states that there are two motivations pushing a consumer to purchase a product: objective and affective criteria. The objective criteria are concerned by the functionalities, performances and cost; the affective criteria are about the feeling, emotions and the personal perception of a product.

Therefore, no one can exactly express these personal criteria except the users themselves. In this case, involving users in the design process is crucial to realise a product answering exactly their requirements and expectations. The main concern is this approach is when to integrate users in the design process and how many times in the life cycle of the project. In other words, design team should be aware where users should be present occasionally in which project phase exactly while designing. They should also well define the users' space of interventions and contribution. The study of Kaulio(Kaulio, 1998) defines the possible degrees of user involvement in the design process: design for users, design with users and design by users. In other words, there are approaches considering the user problems central in the design process, while other approaches involve the users in the co-creation phase such as participatory design. Some design approaches can allow the user playing the role of designer. In the following paragraphs, we detail the well-known user-oriented design approaches. The literature review shows that there are three main trends in the method of considering users in the design: User Centred Design, Participatory Design and Scenario based design.

1. User centred design

User Centred Design (UCD) is considered as a philosophy and a process according to (Katz-Haas, 1998) . He states that "*It is a philosophy that places the person (as opposed to the 'thing') at the center; it is a process that focuses on cognitive factors (such as perception, memory, learning, problem-solving, etc.) as they come into play during peoples' interactions with things*".

The concept of user centred design has come out when researchers brought together collaborative practices and product development (King, Keohane, & Verba, 1994). They define it as a strong commitment of particular user to product design process where the design team tries to deeply understand the empathy of users and give much more attention to their affective values.

From Kaulio's point of view(Kaulio, 1998), despite involving the user, the User Centred Design keeps the roles clear. The designers still the leaders of the task and the users are actors from whom designers can elicitate the requirements of their products. Therefore, User Centred Design is an approach focusing on the users' needs, wishes and limitations.

The international standard ISO 13407 states that the main basis of UCD are regrouped in four points:

- Specification of context of use,
- specification of user and organisation requirements,
- suggesting a design solution
- Finally, evaluating the proposal against the requirement.

User-centred Design stress the necessity to focus on the users issues and ensure to make it central in the whole design process. However, as cited before the Participatory Design (PD) involves users only in co-creation phase.

2. Participatory design

(Beveridge, Claro, Lange, & Vanides, 2005) define Participatory Design (PD) as a set of design practices that integrate users as members of the design team throughout the design process. The purpose of the design is to respond to the real needs of users through a collaborative approach and an interactive process. PD is characterised by the involvement of users from the early design phase and not after production. According to(Schuler & Namioka, 1993) Participatory Design (PD) assumes that the users themselves are the best actors to set the improvement of the product. Therefore, we can define the Participatory design as an approach that tends to integrate the users in the design process, with the aim of shifting the design method from designing for users to designing with users(E. B. Sanders, 2002).

The particularity of PD is that the users are not only actors and source of information, but also they are involved in the decision-making process(Sanoff, 2000). However, as discussed before, involving users in the design process have some risks and may implies some difficulties. For example, designers have knowledge and skills in IT tools; the users often do not have the same level of understanding of technologies. Nevertheless, they represent the target of the product and will use it for their professional aims. They are supposed to be a relevant source for complementary information for the product design. As mentioned before in section II.1 designers and users have difficulties to understand each other. The absence of a common vocabulary can limit the exchange between them (Luck, 2003). The recommendation of Erickson (Erickson, 1995) is that the design group have to develop a common language, thus the communication between different actors can bridge the gap and allow sharing the knowledge.

3. Scenario based design

The scenario is at the core of Scenario-based Design (SBD). It can be defined as a narrative description of usage(Carroll, 2000). In other words, the scenario is an imaginary or real story about users and their activities on their work process but it can also be considered as an object of design (Chin, Rosson, & Carroll, 1997).

Scenario-based Design adopts integrating scenarios to specify the possible usages of a future product through a concrete description. In other words, scenario building provides a narrative description that predict what users will do and experience in particular situations with a new product. This approach can help the design team to understand the use-related constraints earlier in the design process development. The main advantage of scenario-based design is when it is involved for designing new product concepts. In this particular situation, the context of use and the target users are not strictly defined(Heinilä et al., 2005).

The scenarios are considered as representations accessible for both designers and users. These representations can enhance the communication between design actors(Carroll, 2000). However, some studies still consider the SBD approach not reliable to envisage future use possibilities compared to other well specified approaches(Rosson, 2002).

In this section, we describe different approaches considering the users‘ issues in the core of the design process. UCD, PD, and SBD focus on how the designed product can satisfy the users’ needs and user experience with proper performance of a product so it can satisfy and validate the requirements.

We remind that collaborative design is considered as a collective activity of open problem solving. It requires technical and scientific knowledge, models, methods and appropriate tools to support the rich exchange between different design actors. The next section presents the role of digital tools in supporting design activity.

4. Digital tools to support collaborative design activity

1. Introduction on Computer Supported Cooperative Work:

The elaborated state-of-the-art states that collaborative design is a collective activity of open problem solving. As mentioned above, the design activity has social, technical and organisational dimensions. The technical side requires knowledge, models, methods and tools. Design teams involve tools to support collaborative design; IT technology should not only increase the capabilities of specialists, but must also enhance the ability of participants to interact with one another through ICT tools.

Due to the complexity of the collaborative design process, many solutions have been designed to assist stakeholders throughout the project. CSCW Solutions - Computer Supported Collaborative Work-, applied to design, is to study ways to work collaboratively through technologies in a context of product design. This research domain defines the functionalities of a software to help a team to collaborate better; In other words, it defines the functionalities to meet the constraints of collaborative work and the human and social problems that result from the use of new technologies. This domain is inherently interdisciplinary and gathers specialists in computer science, design, sociology, ergonomics and psychology (Carstensen & Schmidt, 1999).

CSCW regroups several approaches. The first type is tele-operational engineering. This approach uses non-specific tools to help collaborative design situations(Longchamp, 2003). It offers different services; it can be audio or video conference system, softwares of sharing-application or shared whiteboard. The study of (Marin, Mechekour, & Masclet, 2006) looks at the effectiveness of these solutions and claims that the existing tools are often not adapted to the design task, and they are especially suffering from a lack of support for rich graphic information exchange.

On the other hand, several studies such as (Sadeghi, 2008)(Hisarciklilar, 2008)have examined the use of specialised tools to assist collaborative design. They focus on how can the CSCW tools facilitate communication between project stakeholders and how can the use of these specific tools facilitate the exchange of information in collaborative design.

In the context of our study, we have introduced a new family of software into the designer tools panel: Spatial Augmented Reality. This new family is based on the use of Information and Communication Technologies (ICT). This responds to the growing need for designers to overcome the difficulties related to the complexity of new design models and to be at the cutting edge of technology.

The studies of (Fussell & Benimoff, 1995) and (Dix, Finlay, Abowd, & Beale, 1998) argue that natural communication is the ideal toward which computer-mediated communication should be directed. The underlying assumption is that the more mediated communication mimics natural communication, the more effective it will be. Therefore, ensuring a communication close to the natural communication is the ultimate goal of the ICT tool, which support collaborative design activity.

The study of (Clark, Chew, Fujimoto, Meyer, & Scherer, 1987) have implemented eight constraints that are imposed by the communication tool on the communication of two individuals (or more). These "constraints" can be considered as characteristics of the tool used:

- Co-presence: As a face-to-face conversation, the ICT tool should allow to the users to share the same physical environment. They can see, hear what everyone is doing and look at easily, and therefore have a very rich awareness of the situation, the environment and the actions of the interlocutor.
- Visibility: participants can see each other without limitation.
- Audibility: participants can communicate by talking to each other. The supports should allow intonations and the rhythm of the exchanges
- Co-temporality: the ICT tool should ensure that a statement is produced at approximately the same time as it is received without delay
- Simultaneity: participants can send and receive immediately and simultaneously documents and verbal exchanges.
- Sequentiality: participants can change their turn normally
- Reviewability: the ICT tool should keep track of messages or discussion steps.
- Reversibility: this constraint is about having a correctible character, modifiability of the produced documents.

These constraints will be considered in our study as characteristic of the intended ICT tool to be used. We will present various technological tools and check if they allow to collaborative design participant a perfect communication and information exchange based on the predefined characteristics.

2. Collaborative design with Virtual Reality tool

In order to go one step forward in fulfilling the requirement exposed in the previous section, virtual reality has been considered as an interesting solution to be tested. We will now be presenting some virtual reality solutions for collaborative design team. These systems are based on a large screen on which an omnidirectional projector displays stereoscopic information. They are based on hardware architectures as presented in the following figure 6:

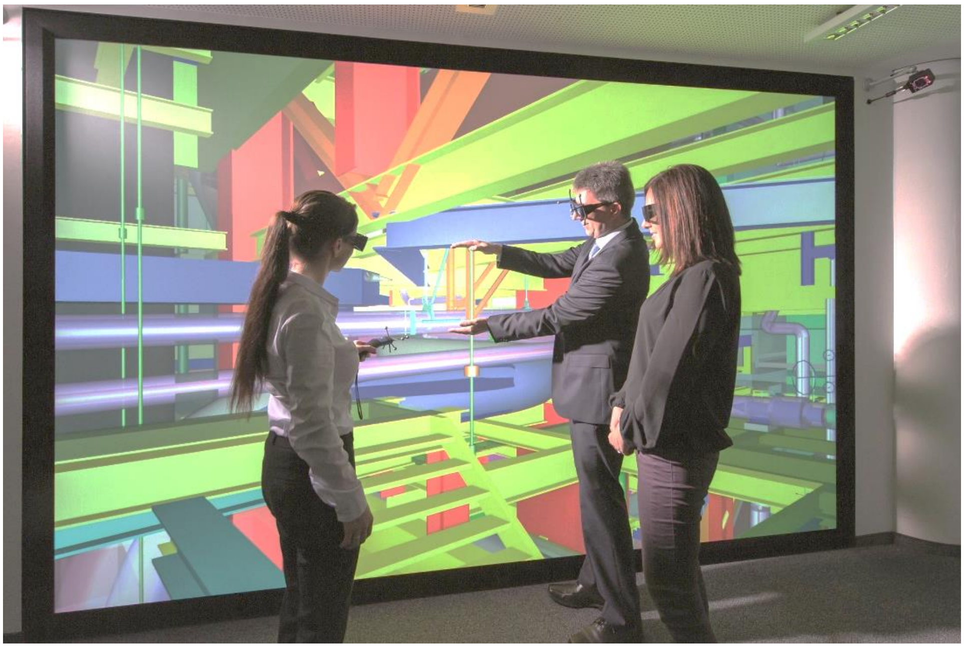


Figure 6. Fakespace Virtual Reality system(“Fakespace Virtual Reality,” n.d.)

Each user is equipped with passive stereoscopic glasses: the system supports a very large number of users. Its use implies the absence of secondary lighting other than the image distribution system; the main disadvantage is that collaboration is limited to verbal exchanges between users. Participants do not share their physical environment either their reaction on discussions exchange. Since the brightness of the room is low (in order to preserve the limited capacity of the projection systems), the communication is done under difficult conditions: in the absence of nonverbal arguments (look, facial expression) and the impossibility of easy access to personal items (notebook, notes, etc.). In addition, the interaction is usually directed by a single mediator or by the use of a collective interface these solutions are generally intended for presentations of scientific documentaries (astronomy, biology, chemistry) or cultural documentaries(Grasset, 2004). Application development and support is largely constrained by the providers of hardware architecture, the solutions remaining proprietary and complex to implement. It also presents a strong limitation due to the high cost of implementation, which remains almost unaffordable for small design companies.

We discuss a second system, which is widely used and popular for immersive applications. A CAVE (or Collaborative Virtual Environment) consists of a cubic space. On 2 to 6 of its faces, a stereo image is retro-projected. The users inside are equipped with stereoscopic glasses and can interact mainly with devices of the pointer, data glove or 3D mouse types (figure 7).

Figure 7. Group of researchers discuss in immersive cave(“Can Virtual Reality Help Optimize Product Engineering, Manufacturing and Operations?,” n.d.) (“immersive cave,” n.d.)

They have an omnidirectional immersion sensation(Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992). Based on the widely used CAVELIB [CAV] library, a large number of applications have been developed: scientific visualisation, architecture, artistic, etc.

This technology is strongly limited by the need to have for each user a point of view according to his position in the CAVE; otherwise, the users must be placed near the one whose head is followed by a sensor. Standing posture and strong immersion limit its use for long sessions. It can imply a lot of fatigue, loss of balance and nausea for beginners. The risk of occlusion limits the movement of users and the lack of physical support reduces the use of natural interfaces and real tools (notebook, notebook, etc.).

Through the presented solutions of Virtual Reality, we can notice that these approaches generally favour the task rather than the participant. They present very intrusive solutions, where the user is equipped with peripheral devices and prevent participants from natural communication.

3. Collaborative design with Augmented Reality tools

The study of (Milgram & Kishimo, 1994) define Mixed Reality (MR) as a technology that combines resources from the physical world with resources from the digital world. The mixed reality environments do not replace the real world as the full digital environments do. Depending on the nature of objects employed whether they are real or digital and depending on the activity, we have several classifications of MR environments.

Augmented reality (AR) is a form of Mixed Reality. The study of Azuma and al. define the Augmented Reality as the technology combining reality and virtuality. AR is characterised by being interactive in real-time and displayed in 3D environment(Azuma et al., 2001).

Figure 8. Milgram's reality–virtuality continuum(Milgram & Kishimo, 1994)

As presented in figure 8, the Reality-Virtuality Continuum proposed by Milgram suggests that Augmented Reality occupies the space between Real and Virtual Environments. In this space, AR is centred between the Augmented Virtuality and the Real Environment.

The form of visualisation in augmented reality are various. In industrial context, the See-Through Augmented Reality (STAR) form is probably the most common one. The specificity of STAR lies in visualising the digital elements through a screen, as illustrated in the example presented in Figure 9.

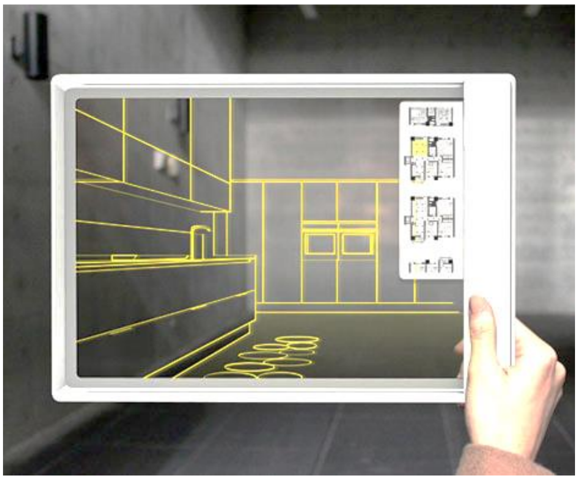


Figure 9.See-through, touch-screen tablet renders interiors in 3D("SEE-THROUGH," n.d.)

Then, the screen could be a Head Mounted Display (HMD), Holographic displays, Smart glasses (Optical see through, Video see through) or Handheld AR. STAR present multiple advantages of visualisation such as high contrast and resolution. Nevertheless, it also shows limitations especially on the number of users: each participant should have his own HMD. In addition, for Handheld AR devices, the user has to carry it along the meeting, which will be tiresome overtime and may present an obstacle to interact with the rest of the environment.

Multiple studies were interested in the potential of augmented reality within group design activities. The research of Billinghurst and al. (2008) investigates the difference between group of designers working with traditional tools and other groups working with AR tools. The study assumes that using AR tools make the task longer comparing to a face-to-face situation. However, results show that more questions were asked while designers involve AR tools. The study concludes that the AR limitation are due to the head-mounted displays used and recommend to use technologies offering more communication facilities such as hand-held AR devices or Spatial augmented reality.

In addition, other studies identify problems related to the involvement of AR technology in design activity. According to (Porter, Marner, Smith, Zucco, & Thomas, 2010) study the main difficulty lies on supporting user interaction with the prototype. (Park & Moon, 2013) highlight the problem of hand occlusions especially when involving low-cost devices or heavy and big equipment to be worn by the participants.

Within the SPARK project, an AR device was suggested as a solution to the previous difficulties. As shown in figure 10, a light tablet is used for tracking and manipulation of AR scene.

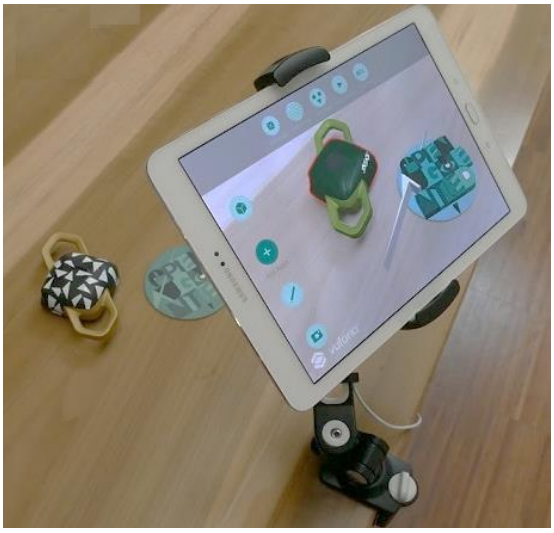


Figure 10. Handheld Augmented Reality device developed within SPARK project

To conclude about the Augmented Reality based system, we can consider it as an approach allowing combination of interactions on virtual elements with the possibility of using real documents, objects to be manipulated. The AR approach provides an extension of the user's tools instead of replacing them, therefore the user adaptation seems easier. The ability to import and export digital or real elements thus avoids imprisonment in a purely virtual space, allowing users access to the possibilities of both worlds. The interaction mechanisms with 3D contents make it possible to import models and to manipulate them but remain however limited to planar transformations(Grasset, 2004). The collaboration is mediated by the conservation and the link between participants are the AR device. In other words, the AR device ensure both the participants interactions and communication.

4. Collaborative design with Spatial Augmented Reality

The book of Bimber and Raskar presents multiple forms of AR approaches. They are classified depending on technology position on the user either it is a hand-held device, head-worn or spatial projection. Contrary to Head Mounted and hand-held AR, the Spatial Augmented Reality (SAR) does not integrate the technology on the user. The user is inside the environment(Bimber & Raskar, 2005). The most popular technology to implement SAR is through the projection of images onto physical objects and is also known as projective SAR(Furht, 2011).

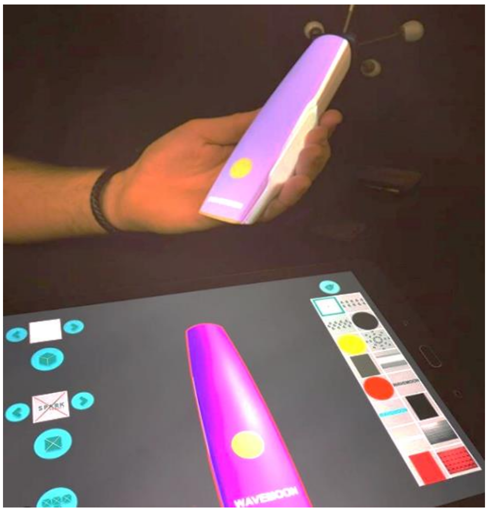


Figure 11. SPARK SAR application

Multiple studies investigate the relevance of involving SAR technology to support collaborative design sessions. The advantage of this technology is that the user is not constrained to see the augmented world through a monitor. And there is no obligation to wear head mounted displays or hold hand devices which is an ergonomic limitation of conventional AR display systems (Bimber & Raskar, 2005).

- Applications of SAR in collaborative Design:

One of the assumptions about the application of SAR in design is that it will allow participants in a design session to communicate more naturally, limiting the inconvenience of head mounted displays underlined before. The study of O'hare and al. (O'Hare, Dekoninck, Giunta, Boujut, & Becattini, 2018)is evaluating the impact of SAR in the novelty and quality of ideas comparing to usual design sessions. The results of this study reveal that SAR increase the novelty and quality of ideas however it spots the complexity of the set up process for a collaborative session. These results are confirmed also in the study of Akaoka, Ginn and Vertegaal (Akaoka et al., 2010) which highlight that SAR environments require an exhaustive implementation and configuration, but they confirm that participants are satisfied with the interaction in such environment. Their research method was based on using SAR technology in student group design projects to project graphics and user interface elements on to physical, low-cost prototypes. Students confirm that the interactive hands-on approach and the ability to change elements quickly are important features. However, they spot the problem of hand occlusions.

As cited before, the study of (Porter et al., 2010) highlights the AR difficulties to support user interactions and suggest SAR as solution. They propose a prototyping system allowing evaluating the interactive functionalities of a product such as buttons before electronics are incorporated into the prototypes. Their method is based on a finger tracking SAR system and is compared to a traditional system. They conclude that in both contexts users were able to carry out the evaluation and were able to contribute in improving their design. However, SAR system enables more iteration per timeframe and allow integration of end-user feedback early in the design process. Many participants felt that SAR ensure good visual representation of the concept, and they conclude that SAR technology might be useful as a design tool.

The study of Irlitti & Von Itzstein,(Irlitti & Itzstein, 2013) underlined a major advantage of the SAR technology that it is able to offer both flexibility through immediate modifications of the visuals and real-time feedback and affordance thanks to the presence of the physical object in the scene. This study was based on gathering feedbacks from three design experts on the added value of applying SAR technology on collaborative design activity. The authors reported, "*Design experts see potential in leveraging SAR to assist in the collaborative process during industrial design sessions, (…) presenting an enhanced insight into critical design decisions to the projects stakeholders. Through the rich availability of affordance in SAR, designers and stakeholders have the opportunity to see first-hand the effects of the proposed design while considering both the ergonomic and safety requirements."* (Irlitti & Itzstein, 2013).

Complementary to these cited research works, the study of Ben Rajeb et al. conducted in 2014 was focused on the SAR impact on collective reflection in design projects. They highlight how "*SAR participate perfectly in group cohesion by creating intermediary spatialities between augmented presence and virtual co-presence. They aid and equip the student in learning how to collaborate. They encourage peer-to-peer sharing between learners, trainers and experts, but at the expense of independent work and the creation of private conversations.*"(Ben Rajeb & Leclercq, 2014). Therefore, SAR seemed to be an appropriate technology to support collaborative processes.

We can conclude that the involvement of SAR seems to be a promising technology to support collaborative design sessions.

The mentioned studies share the affirmation of a significant potential for the applications involving SAR technologies when designers work together in evaluation and usability phase. Therefore, SAR offers various advantages, which could reduce the challenges of collaborative design sessions. They allow visualisation of generated ideas during the design meeting, thanks to real-time modifications. In addition, SAR potentially allows a real-time modification of design representation to be shared by all participants. It specifically offers direct visualisation, direct manipulation and quick evaluation of the design representation. In conclusion, the SAR technology allows a better user participation in design tasks.

However, we can notice that a limited number of tools have been tested, and we find a little number of works on the use SAR technologies within the context of collaborative design when designers involve stakeholders (non-designers)(O'Hare et al., 2018).

As part of the SPARK project, which is introduced in the following section we will try to present an SAR tool that addresses this gap. Considering SAR technology as a potential technology to bridge the difficulties faced in collaborative design task, in the next chapter we will present the software and hardware architecture of the SPARK platform.

CHAPTER II: An Spatial Augmented Reality platform as a tool to support collaborative design sessions

Abstract

The above mentioned state of the art underlines the importance of non-invasive technological tools to support the collaborative design activities. Through this chapter, we present the SPARK platform which is an ICT platform developed within the SPARK project (H2020). The hypothesis of the project considers the SAR platform as an efficient and adequate tool to be used in collaborative design session. It assumes that it can help the design actors to express and present their ideas in a collaboratively.

We define the SPARK platform as a responsive and intuitive ICT tool that exploits the potential of Spatial Augmented Reality (SAR) technology. The aim is to stimulate the collaboration among designers and stakeholders during the conception of new ideas.

This chapter introduces the SPARK platform architecture from two points of view: first, from the hardware perspective where we detail the used devices and equipment and how we set up the physical architecture of SPARK, second, form the software perspective describing different modules and their functions. The SPARK platform is composed of mainly visualisation, tracking, interaction modules and an Information System. We will present in detail for each module its execution requirements and specific operations. Then, how they interact and share data.

Finally, we describe the preparation and execution of a collaborative design session supported by the SPARK platform.

1. Context and Assumptions of the SPARK project

1. Introduction

Representing ideas with the adequate tool is crucial in the design process. For some years now, new technologies have brought new tools allowing different types of representation of a product and in particular its shape and appearance. For example, 3D modelling of physical objects allow its visualisation on a screen, or in a virtual reality headset. These kinds of representations are closer to the real world more than the two-dimensional sketch or drawings. They also allow a more realistic perception of future products. The uses of these digital technologies have important advantages such as saving time and cost compared to physical prototyping or modelling, since no material transformation is necessary. Following our state of the art, this last point can however be seen as a drawback since these technologies do not allow manipulation and physical interaction with the object, which can however be interesting for the generation as for the transmission of idea.

The European project SPARK (SPatial Augmented Reality as a Key for co-creativity) aimed to propose a new tool for these representations, which reduces the number of printed prototypes to be made, while allowing a physical interaction with the object. This tool is a Spatial Augmented Reality (SAR) platform, which gather different sub-systems allowing a design session to take place. This platform proposes to project in real time digital design elements on a physical prototype.

2. Context and aim of SPARK project

The SPARK project (H2020) was a three-year, research project which exploited the potential of Spatial Augmented Reality to develop a responsive ICT platform in order to support and stimulate the collaborative creative thinking in the design process. The aim was to reduce language barriers and knowledge gap between different design stakeholders who may have diverse backgrounds and skills(O'Hare et al., 2018). The SPARK project assumed that the Spatial Augmented Reality technology can enhance the innovation capabilities of creative industries. The platform could facilitate the brainstorming phase, which leads to a faster assessment of design solutions in a co-design environment. The project focussed more on the products and packaging design fields, which are also called creative industries. These domains require an important number of printed and realised physical prototypes. Therefore, including a platform that could show final product suggestions in real time will reduce the need to printed prototypes and would save time and money.

The aim of the SPARK project was to develop the design process by integrating the design agencies' clients and/or the end-users in the early phases of the process. In other words, the goal was to foster the collaborative design practices since the first phases of design process. This aim can be achieved thanks to the use of Spatial Augmented Reality technology, which allows the designers to apply in real time the customers' suggestions. Therefore, the design team have the chance to take advantage of the SAR technology to easily gather immediate feedback on what they propose and discuss. They can also limit the number of iterations of product design, which clearly improve the project development.

The platform enables design actors to interact with a mixed prototype of a rough shape of the product the designers intend to develop. We define the mixed prototype as the combination of a physical prototype and a digital projection(Becattini et al., 2017). The physical part is a 3D printed shape of the intended product. The digital part is the 3D projection of graphical design elements that can visualise colours, images and textures. The combination of both aspect of mixed prototype allows the final product to be displayed to designers and customers since the early stage of product development.

The SPARK platform is based on multi-projector visualisation system, a tracking system based on infrared optical cameras; the designer uses a tablet interface as presented in figure 12 that can be used to modify the digital content and an information system playing the role of a database that manages the digital assets and allows the storage of completed sessions.

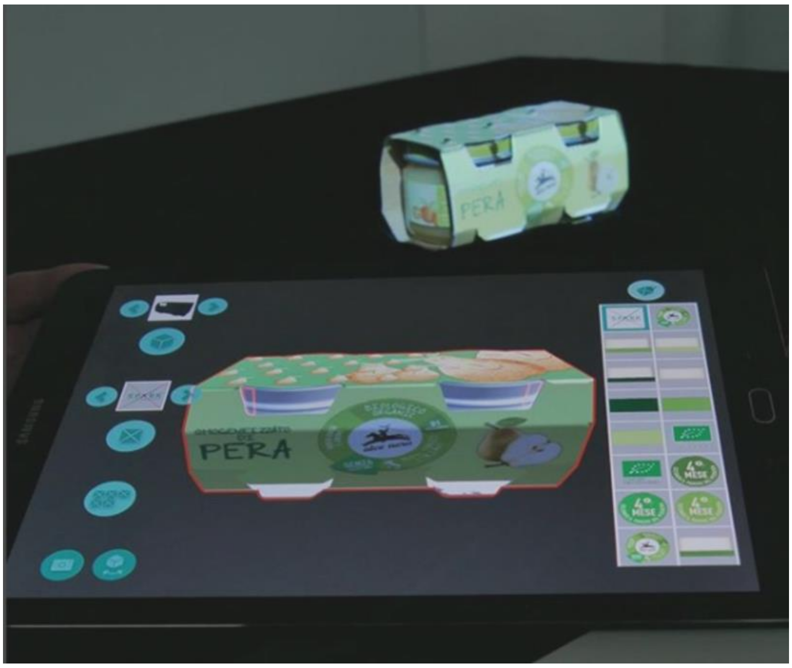


Figure 12. The SPARK tablet PC-based user interface (foreground) and SAR model (background)(O'Hare et al., 2018)

3. Assumptions of SPARK project

According to the literature review established by the project partners, the SPARK project proposal is based on the following assumptions:

- Creative stimulation:

Various design researches study the role of creative stimuli and assume its effectiveness in removing design fixation. (Raghavan & Cafeo, 2009) confirm that supporting inspiration for creativity goes through providing stimuli.

The SPARK project considers the mixed prototype of the Spatial Augmented reality platform as a stimulus. The project assumes that the involvement of mixed prototype is considered as a stimulus for the co-creative design team. The digital elements (assets) projected on the physical artefact allow a natural interaction through the physical prototype and can change the routine thinking of the designers.

- Co-creation and co-design:

Among the leading business trends, we can cite co-creation and co-design, which implies that an important number of design companies apply, innovation methods in their business development.

The study of Sanders and Stappers(E. B.-N. Sanders & Stappers, 2008) suggest definitions for these two important terms. They consider that co-creation is any act referring to collective creativity, in other words, any shared creativity action by two or more people. This study also states a definition of co-design as the application of collaborative creation during the entire design process. They assume that co-design is "*… collective creativity as it is applied across the whole span of a design process*". The SPARK project assumes that the SPARK platform will facilitate the interactions between designers and customers but also the direct interaction with mixed prototype. This facilitation will have direct influence and improvement on the design process progress.

- Workplace innovation

The SPARK project assumes that introducing the SPARK platform developed along the project will enhance the productivity of the workplace. In other words, while a creative company equips its own workspace within the SPARK platform, the design team will be more efficient. They will keep working in the same area but with the potential functionalities offered by the SPARK platform. It will help the design team to easily introduce their external stakeholders and get them involved in the collaborative design task.

- Innovation and Customer Involvement

As cited before the trends of co-creation and co-design mean involving the customers in the creative innovative process. The SPARK project assumes that integrating their platform in the design process will guarantee a key to improve the experience of external stakeholders. Therefore, the participation of customers (or/and end-users) in the design task will implies a future product which more accurately fits the needs of potential users. The SPARK platform will facilitate the exchange between the design actors and allow a real time evaluation of proposed ideas.

2. Integration of SPARK Hardware & Software modules

This second part is dedicated to first, describe the hardware setup of the platform. Then, detail the functionalities and features of software modules. Diverse modules compose the SPARK platform.

1. SPARK Platform Hardware architecture

The Figure 13 presents the architecture of the SPARK platform installed in our GSCOP lab. The main components are highlighted in the black boxes. The front-end components are the mixed prototype and the interaction device, which is a tablet. These components can be used by the participants of collaborative design sessions. The back-end technologies is composed of two projectors and the infrared cameras (6 in our case) forming the tracking system and a desktop computer. In addition to the SAR software the information system (IS) manages the data.

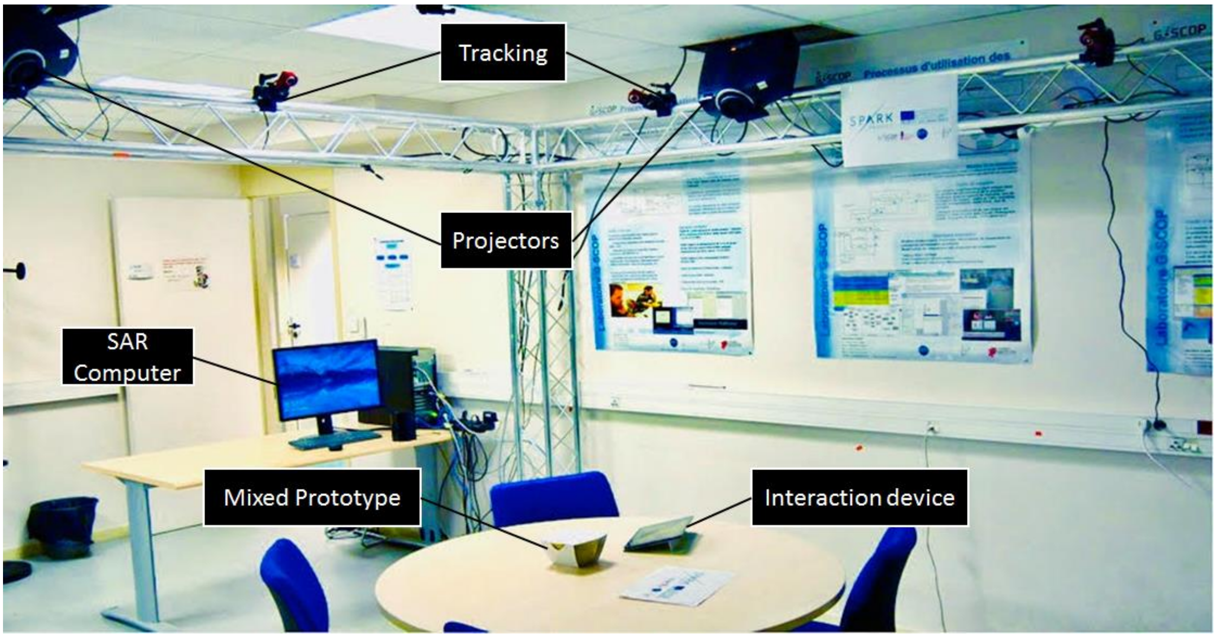


Figure 13. Picture of the Grenoble INP SPARK platform

The SPARK platform integrates:

- **A SAR application**: The SAR module should imply a high performance computer. This SAR computer will be in charge of running the 3D scenes, manage the number of projectors that are connected. It can vary from two to N projectors; it depends on each company needs and space of work. Therefore, the computer setup should be equipped with enough graphic output ports to connect multiple projectors with high resolution.
- **The multi-projection system**: The several projectors (2 here) are connected to the SAR computer. The SAR module decides which images will be displayed at each projector device. The multi-projection system is in charge of the correct rendering of the digital elements onto the surface of the neutral tracked prototype.
- **The optical tracking system**: based on Optitrack technology, it allows the tracking of the position of the physical mock-up based on a pre-calibrated reference system. The tracking information is communicated to the SAR module in order to update the real-time projection with the adequate position information. It implies several infra-red cameras with discrete markers fixed on the top and edges of the prototypes to be designed.
- **The Physical structure**: it is the structure, which supports the hardware equipment of the SPARK platform. Each partner of SPARK project should place it in a called SPARK room. The

physical structure fix the projectors and the tracking cameras. The following figure 14 shows a possible layout of a two-projectors configuration of the SPARK meeting room:

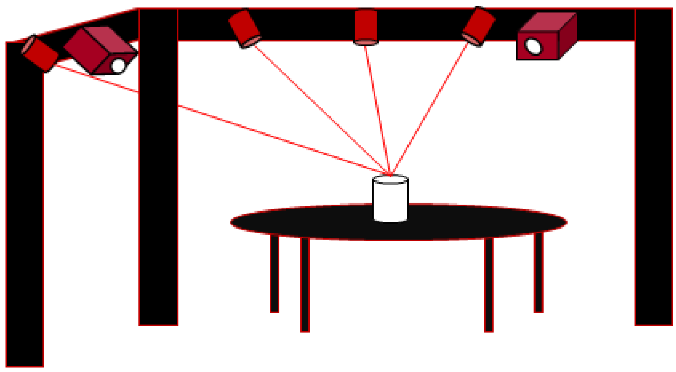


Figure 14. Physical structure of SPARK platform in GINP lab

- **A web application**: **the information system** It is a web server run in the cloud. It requires a computer equipped by a HTTP protocol. The main function is to ensure the data management of all graphical elements (images, textures, texts, 2D and 3D objects.). The designers through a special administrator interface upload these contents before the starting of the collaborative design session.
- **The interaction device** (Tablet) The main role is to ensure interactions in the SAR environment. The interaction device allows the user to modify the graphical elements present on the interface. The Android application running on the device is based on multi-touch gestures approach. While working on this device, the user is not manipulating the 3D object. Instead, it is an extension of the SAR module to let the user easily perform the functions provided by the application. The SAR computer play the role of a server and the interactive devices as the client. Information about the fingers' position and the functions' activation are sent in real-time from the client to the server.
- **The physical prototype**: a 3D printed prototype presenting the intended product. It is updated in real-time with the suggestions of design discussion. It can also be hold between hands of participants in case of need.

We present on the following Figure 15 a summary of how SPARK platform hardware components are organised and connected between each other during a collaborative design session.

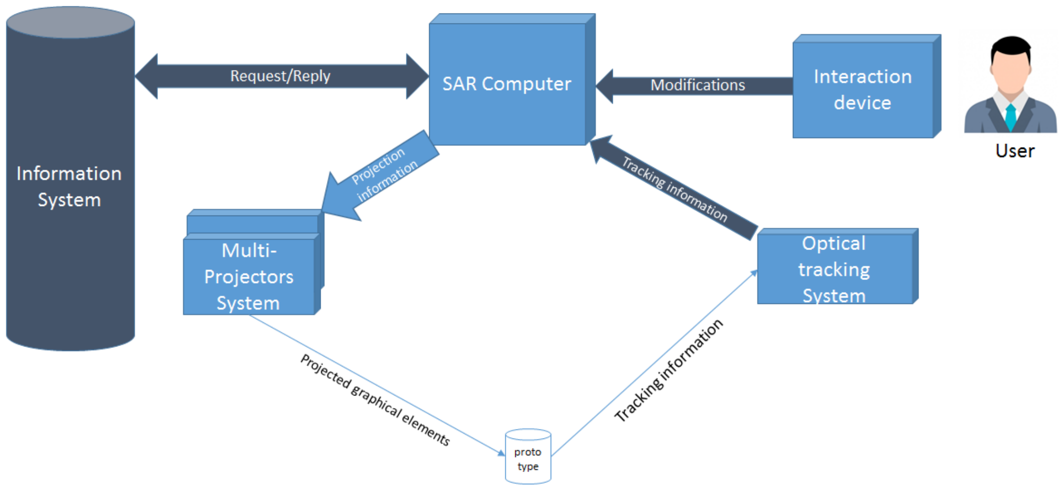


Figure 15. Connexion between different hardware modules of SPARK platform.

2. SPARK platform Software Architecture

The research studies related to augmented reality suggest the necessary technologies to build an augmented reality application. In their study Zhou and al. (Zhou, Dun, & Billinghurst, 2008) review ten years of augmented reality papers, they state that tracking, interactions and display technology are the most important topics in this research field. The proposed SPARK platform incorporates all these fundamental components. We add to these modules, an information System which is a web application to manage the content of sessions. In the next paragraph we will detail the SPARK software modules one by one and expose their functional role in the platform.

a. Visualisation module

The SAR visualisation module render in real-time the generated virtual images correctly on the external surface of physical prototype. Since SPARK platform, envisage the use of multiple projectors in order to cover 360° of the design-meeting table. The second main function is to smooth and equalise the overlapping region with developed image processing algorithms. Therefore, the visualisation requires the use of one or more video projectors. These video projectors will have impact on the projection quality, which strongly depend on their performances. In order to choose the most suitable video projector for our SPARK room in GINP lab, several types of projectors have been tested in order to understand their internal parameters impact on the final projection. Finally, we have picked the Barco F50 video projector illustrated in the following figure 16:

Figure 16. Barco F50 video projector used in GINP Lab

This choice was based on Barco F50 parameters. It is the world's first lamp-based single-chip DLP® projector that combines native WQXGA (2,560 x 1,600) and Panorama (2,560 x 1,080) resolution with active 3D stereo and high frame rates. The DLP technology ensures a low visibility of the pixels borders and a higher contrast. Despite the good performance of the projector parameters, the platform could include the use of multiple video projectors, so it is important to ensure the synchronisation of the multiple devices. Consequently, we should set up a calibration procedure to control the projected graphical elements according to the position, orientation of physical prototype and to the dimension of the projection area. Then, we should also manage the multiple projection procedure.

- Projector calibration

We fix in the top of each projector, a webcam (RGB camera) and apply an algorithm based on structured light. The aim is extracting the intrinsic and extrinsic parameters of each projector.

i. Intrinsic video projector calibration

The calibration procedure starts with lights projection and capture of patterns depending on the resolution of the projector and the following chessboard corners:

Figure 17. A photo of calibration camera-projector using the structured light algorithm

This step is mandatory for each video projector to be used in the SAR scene. In case of any modifications on calibrated video projectors such as changing the position, changing the lens parameters, zooming in/out, it is then necessary to repeat this calibration procedure. For each calibration, at least five captures are recommended to be realised as presented in the following figure 18. The projected image should cover the entire printed chessboard, the camera fixed on the top of project should easily recognise the corner of the chessboard and allow capturing high and low-brightness conditions.

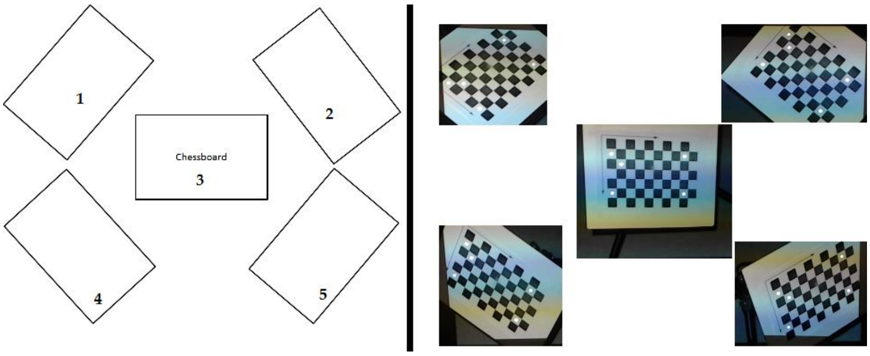


Figure 18. Projector intrinsic calibration- First Step

At the end of the process, we identify the parameters of the projector, which are the shape of the projection cone and its position and orientation. Within the project, we developed a tool that allows a second verification of the gathered parameters. The script projects a red rectangle on the target chessboard. We check if the red rectangle corners match exactly with the internal corners of the chessboard, as presented in the following figure 19.

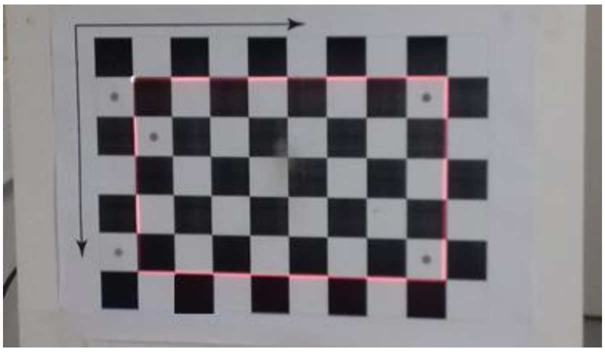


Figure 19. Projector intrinsic calibration- Second Step

ii. Extrinsic video projector calibration

To correctly render the images to be projected onto the physical prototype, we need to determine both the intrinsic parameters (addressed in the previous paragraph) and the extrinsic parameters. In other words, we should compute the projection matrix, which defines the position and orientation of the virtual rendering camera inside the 3D unity scene, corresponding to the location of the projector inside the tracked interaction space. This step allows to exactly superimposing virtual 3D geometry on its real counter-part without any pre-warping. This step is strongly related to tracking system (presented in the next section).

- Multi-projection calibration

The calibration of multi-projection system demands a separate calibration of each video projector to be used in the SAR scene. Therefore, for each single projector it is necessary to obtain the intrinsic and extrinsic parameters. In other words, we should properly define the projection volume and the location of each projector, as described in previous sections. Multi-projection system face a main problem that is the managing of overlapping area and gaps as presented in the following figure:

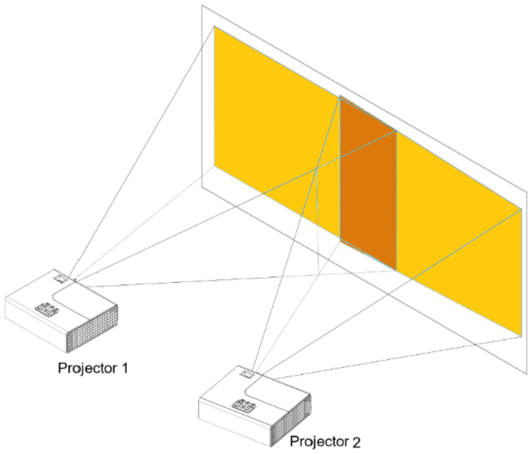


Figure 20. Multi-projection area and overlapping

Within SPARK platform, we need a solution in order to mix the projection of at least two video projectors on the physical prototype. The first solution proposed is the visualisation with sharp edges mixing which is splitting the images produced by the two projectors without overlapping. In this case, the application will decide for each pixel will be displayed through which video projector. The second suggestion is the most suitable mixing procedure: the smooth blending; the technique behind is to smoothly blend the images projected by the projectors. The aim is to hide completely the misalignment between the two images projected.

b. Tracking module

SPARK tracking module is based on an array of Flex 6 Infrared (IR) cameras capable to detect spherical or hemispherical reflective markers placed on the external surface of the physical prototypes.

Figure 21. Flex Infrared cameras

The main functionalities of tracking system are:

- The recognition of any type of uniform surface objects present in the tracking area
- The identification objects parameters: the position and orientation in the scene.

The SPARK area of work will involve user direct manipulation with physical prototypes. Therefore, the tracking system should be capable of decreasing the risk of occlusion due to the user's direct manipulation. This criterion is one of the advantages of the chosen technology (Flex 3 IR cameras). Despite the complexity of their setup, since each camera should be fixed individually and serially connected with the others. The IR cameras require also an initial calibration, managed by Motive software propriety of OptiTrack. First, it is needed to determine the position and orientation of every OptiTrack camera used. The procedure starts with the calibration 'wand', which is the calibration of the whole trackable environment formed by the present IR cameras. Motive algorithms calculate the relative position and orientation of each camera. It also provides some values describing the quality of the calibration:

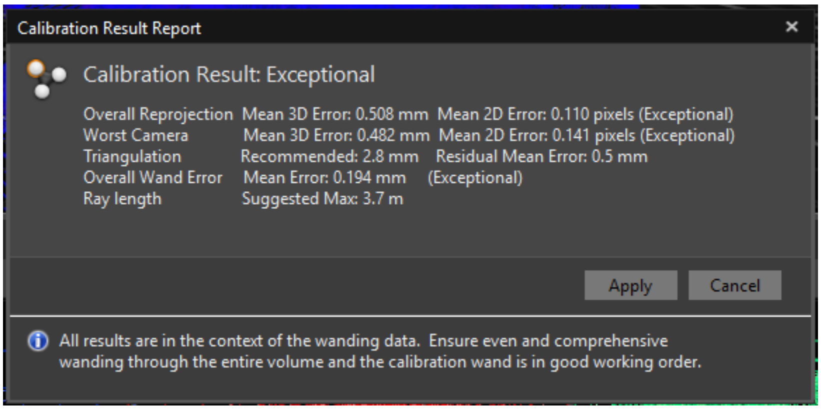


Figure 22. Result of tracking environment calibration (Wanding)

Then, it is necessary to define the ground plane and (x, y, z) axis, in order to define the scene. This step is supported by the calibration square included in OptiTrack package. The definition of the coordinate system of our scene, will allow finding the origin (0, 0, 0) orientation of each artefact more easily.

The chosen tracking system presents many advantages such as a wide tracking volume, high precision but the most important ones are the stability of the tracking and the reduced risk of occlusions with other elements present in the scene(such as users hands, reflective materials..). In SAR applications, we need a reliable tracking technology that can ensure a perfect alignment of projected images onto physical prototypes.

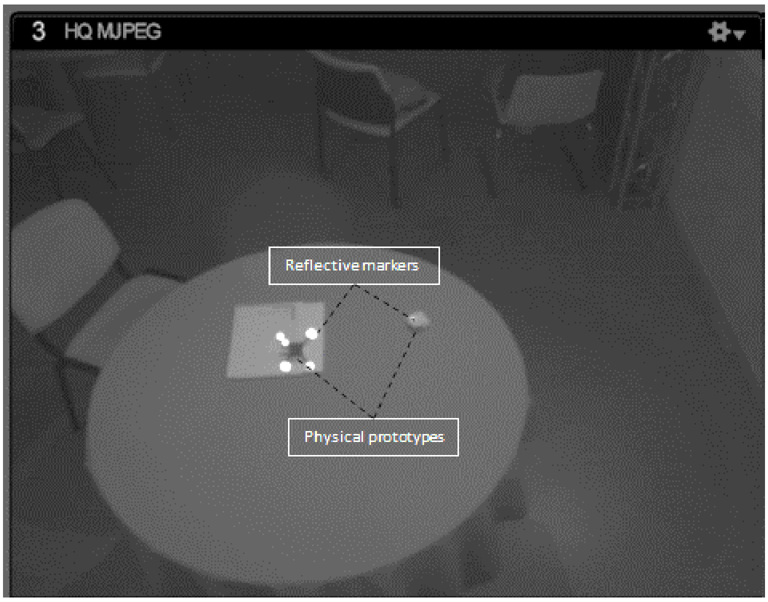


Figure 23. Captured image from Infra-red camera in SAR scene

c. Interaction module

The interaction modules include all the communication channels allowing the user to interact with the SPARK platform, i.e. manipulating the mixed prototype through the interface of the application which gives access to manage the 3D models, static and animated images, textures, texts. Or a direct manipulation of the physical prototype. As presented in the visualisation section, the mixed prototype can be freely handled by the participants. Since the prototype is tracked with markers, the projection will follow the prototype position and keep being updated in real time.

The interaction with the interface is ensured via a touch device, in our case in GINP lab we choose to perform it through a Samsung Galaxy Tablet S2 with a 9,7'' sAMOLED display (2048x1536). The interface suggests functionalities related to manage the content of packaging design task. The idea behind this touch interface was keeping a usual interface of 3D modelling software so designers will feel quickly familiar with our SPARK interface.

We present the three main functions of Graphical User Interface displayed on the tablet: the main functions menu, the contextual menu and the visualisation menu:

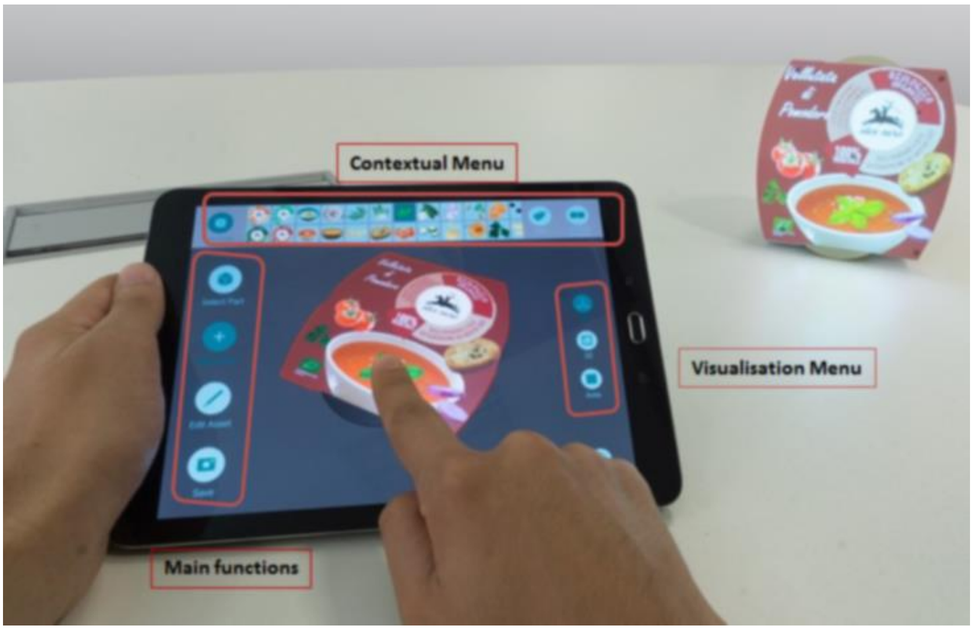


Figure 24. Tablet interface -Detailed menus

- The contextual menu present in the top of the tablet (figure 24) displays details information or functionalities
- The main function menu allows the user to execute the design task: select the mesh to work on, select from the assets library the item to be added and then modify the size, rotation, position and layer.
- On the right of the screen, we set three visualisation settings. We explain the difference in the following paragraph.

Three visualisations interfaces are proposed to manipulate the digital content:

- 3D view: three-dimensional render of the virtual prototype
- UV map view bi-dimensional unwrap of the prototype's mesh
- Touch area view: a graphic simulation of trackpads

Figure 25. The GUI layouts: 3D view (left) UV map (middle) Touch area (Right)

The 3D view presents a standard and realistic representation of 3D model. The user can apply operations directly on the representation of mixed prototype.

The UV map view: designed to be similar to the professional tools used by designers. The user places graphical elements on a 2D representation of the prototype. If the participants choose this layout, they will need to check their modifications rendering on the mixed prototype.

The *touch area view*: adopting this layout, participants can only manipulate the digital content without any visual feedback. They have to follow their modifications on the mixed prototype since it is the only available visual output.

d. Information System (IS) module

SPARK platform consists of two mains modules: SAR module (visualisation, tracking and interactions) and the second one is the Information System module. The main function of this module is to manage the data used during the sessions, including the digital representations of the artefacts, the assets and the initial set up of the proposed solutions that will be discussed during the sessions. IS consists of a web application that allows the designer an agile set up and sharing of the sessions. In this paragraph, we will focus on the front-end of the information system that is the web-application that was designed to conduct collaborative design sessions.

The IS module allows preparing and launch a collaborative design session, administrate participants for a session, and to prepare the files to be used during the session. It also records the events and the decisions made that are delivered in a report. The IS is important before the session and after the session.

In this section, we will detail the steps of session preparation before setting up the meeting with clients. Designers take in charge the preparation phase where they arrange the necessary documents, materials before launching a live session where all design actors can collaborate around a prepared proposal of future product.

i. Assets management

The information system proposed to the designers (who are leader of session) an asset library, which is a storage space of all their projects' documents and objects as present in Figure 26. We define assets as all the elements to be involved in collaborative design session. It could be 2D images, 3D objects models, textures, Fonts and text. All these cited elements can be projected on the surface of the physical prototype while running the session. Since we have several partners to deal with the IS, we organise the asset library in a hierarchical architecture by clients, then for each partner (client) they are organized by products for each project. Therefore, designers can upload new assets in case of need or edit existing ones, deleting the useless assets, edit the asset information and download the asset image file.

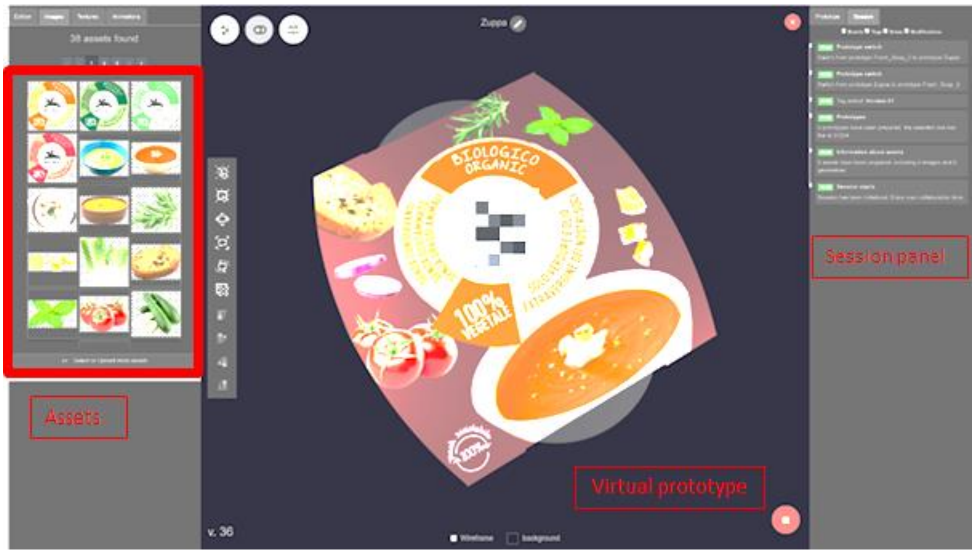


Figure 26. Editing interface of virtual prototype with assets and session panel

ii. Collaborative design sessions management

The information system allows the creation of a collaborative design session and associate a client and a product for each session. However, participants of the session do not have the same access rights. The IS define different user profile:

- Leader: full access rights
- Designer: cannot add/remove participants, or update their profiles;
- Attendee: viewing rights during a live session, upload information to session (notes, posts, files).

Therefore, the session leader when setting-up a session should define: who are the participants to collaborate under the session. Then, prepare the virtual prototypes: he built it using the uploaded assets so participants can manipulated it during the session. The leader defines the design task to be performed during the meeting. Finally, set up a whiteboard to enable sharing notes, posts and files between participants.

A collaborative design session has three possible states:

- In preparation: before starting the meeting while the leader create the content, add the adequate participants, define the design task, and build the prototype
- Live session: During the meeting, once the design team launch the session where all participant collaborate around a prototype;
- Done/Review: After the meeting, a detailed session report is delivered so design team can review the most important point of the discussion. They also can create a new session out of a step in the existing session.

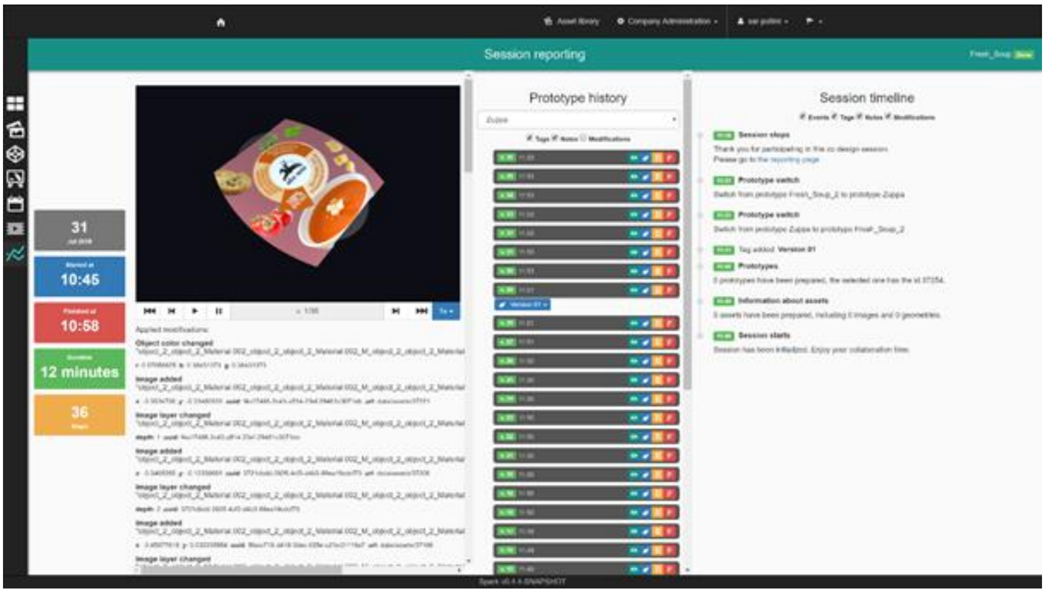


Figure 27. Screen shot of Information System- Reporting tool

3. Execution of collaborative design sessions supported by SPARK platform

In the following paragraph, based on figure 28, we describe how a collaborative design session is prepared and executed. Basically, the designer starts by creating under 3D and 2D modelling software all the needed digital content of the session and especially the digital model of the product. Then, he prepares a physical model of the product. In most cases, the designer uses rapid prototyping technique for the physical representation in order to have a neutral and white prototype. Now the team prepares the room session. They calibrate the video projectors, set up the tracking system and generate calibration files to integrate them as setup data into the SAR computer. The 3D model of the product is uploaded into the SAR system and the physical model is equipped with infrared markers. Finally, the designer uploads all the prepared assets (3D models and graphic elements: logos, textures, images) on the Information System and initialises a new session; The SAR system downloads all the assets to have them available in the SAR environment and the session can be launched. Designers and their clients collaborate around the mixed prototype, exchange ideas and improve the suggested proposal using the tablet interface. At the end of session, designers can go back to the reporting tool in the Information system to check detailed steps of their sessions.

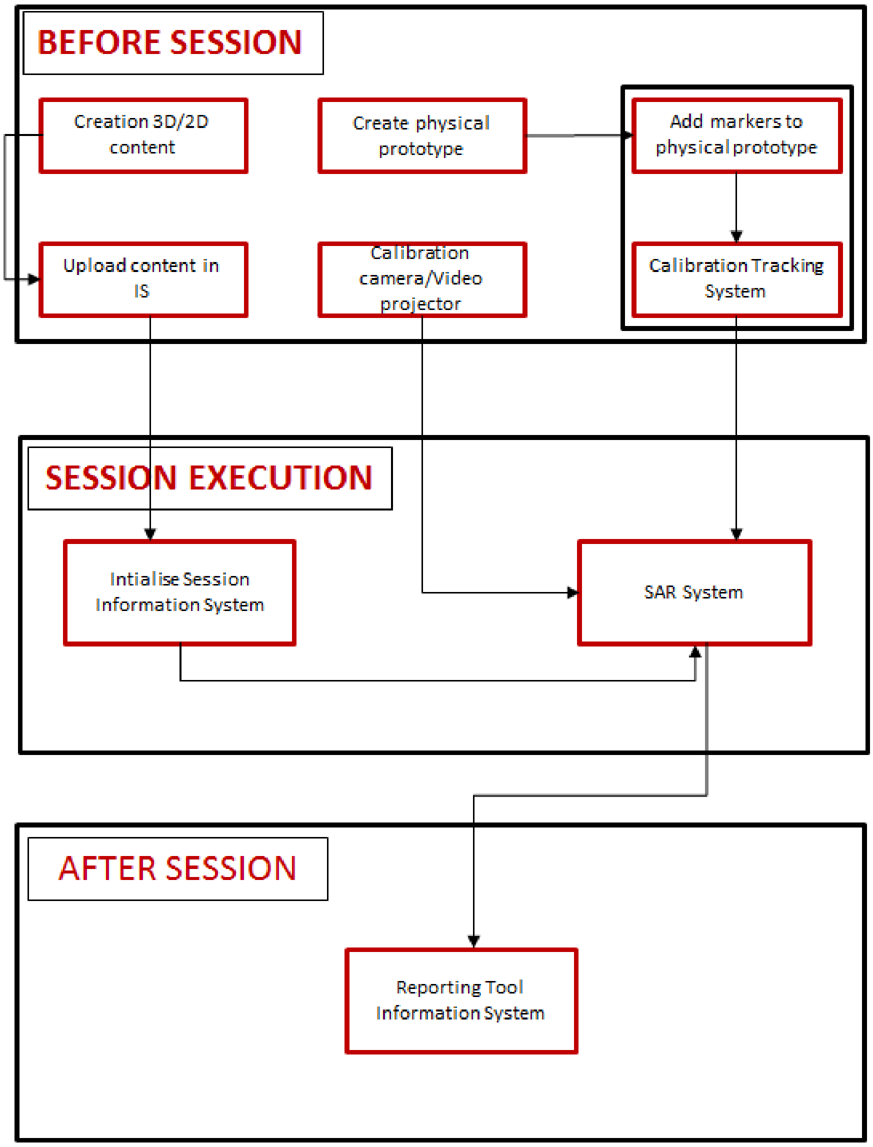


Figure 28. Conduct of collaborative design session supported by SPARK Platform

CHAPTER III:
Research Problem & Question: different supports for collaborative design interactions

Abstract

The third and last chapter of our first part presents the research problem and questions. First, we start with a detailed state-of-the-art in which we discuss the different supports for collaborative design interactions. We focus on the role artefacts play in this field. We present and discuss based on several research studies the different classifications of design artefacts. The concept of intermediary objects, which define artefacts as a representation of future product but also a vector of communication and mediation between design actors. Then we present the concept of boundary objects, which are artefacts of multi-skilled environment. If we consider the limit of each field of expertise, these boundary objects are produced to link between different areas. The last concept we approach is the shared presentations that aim at establishing a common ground in order to clarify and avoid disagreement.

The second part of the chapter presents the research problem. We focus on the communicative role the artefacts play on collaborative design interactions. We present previous research studies related to this field. Then, we present our research questions that highlight the role of Spatial Augmented Reality artefact in collaborative design interactions and its impact on end-users enhancement in the collaborative design activity.

The last part is dedicated to a controlled study that we suggest testing the validity of our research problem. We start by presenting the study, the experimental conditions and how we proceed it. Then through the results of this pilot study, we spot the importance of Spatial Augmented reality artefact in communication and also as a support for collaborative design interactions.

1. Role of artefacts in collaborative design interactions

The design process shows a very fast evolution strongly related to the technical evolution of the companies and the tools involved for the accomplishment of design task. The rate and quality of information that stakeholders accumulate during this process is changing due to the variation of tools and technologies employed. This evolution implies that artefacts involved during the design meetings are also changing. Design artefacts were a subject of various research studies. Many researchers assume that analysing the design artefacts during design meetings can provide a more in-depth understanding of the design activity. We will present the state of the art of research studies highlighting the importance of artefacts in the design activity.

1. Concept of intermediary object

Many studies adopt the methodology for analysing product design process from the objects build within the design action ((Jeantet, 1998), (J.-F. Boujut & Blanco, 2003)). However, even before the cited studies, (Vinck & Jeantet, 1995) had named these design objects, *the Intermediary Objects (IO)*. They define all the artefacts produced during the process and mobilised in the interactions as Intermediary Objects. These objects regroup all the documents, drawings, virtual or physical models, sketches, digital 2D or/and 3D models involved in design activity. The different forms that describe the concept or allow the development of ideas around the product are intermediate as soon as the object is produced and enters into use.

In the work of Jeantet and Vinck(Vinck & Jeantet, 1995)(Jeantet, 1998), the role of intermediary objects is the representation of the future product. They are considered as vectors of communication and mediation between design actors. Vinck and Jeantet (Vinck & Jeantet, 1995)deepen the idea of intermediary object by defining their characteristics in different design situations. These features are both related to the properties of the objects themselves and the situations in which they are used. The authors define two axes to characterise the objects:

- the degree of freedom that the actors have on the object : open / closed,
- Its role in the evolution of the design task: commissioner / mediator.

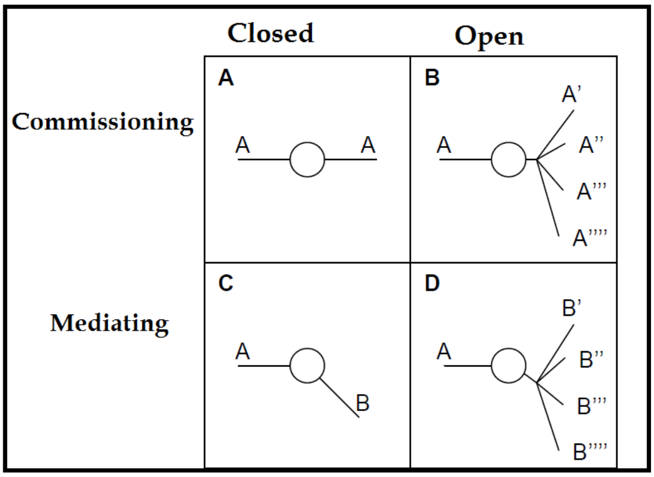


Figure 29. Characterisation of the role of objects according to(Vinck & Jeantet, 1995)

An intermediary object is a commissioning when it has a role of prescription for its user, and is compatible with the intention that presides over its conception. In other words, the intermediary commissioning object allows the passage of an idea to its realisation.

On the other hand, the active role (mediator) of an intermediary object is to defend the idea that the creation of an object is inevitably a transformation of the intention of its creator. A prototype, for example, is not only an act of giving shape to what was drawn on paper before, but it is a new version of the final product, which specifies certain aspects of the product and modifies others. Then the mediating objects, once created, introduce new constraints, limit the possibilities of action, include or exclude future possibilities. They affect the context of the design as do human actors.

Therefore, the degree of freedom is considering an intermediary object as closed, when it imposes to its user the means to interpret it or to act while using it. On the other hand, Vinck and Jeantet argue that there is always a flexibility of interpretation in the use of objects. An intermediary object is open, if it offers these users' flexibility of interpretation or modification.

The notions open / closed and mediator / commissioner are fundamental if we want to associate communication needs and communication situations with objects to improve communication.

The analysis of these Intermediary Objects in various design studies has shown that they play a role of representing ideas, translation and or mediation between design actors. According to Jeantet(Jeantet, 1998) the translation operation consists of transiting from one product state to another with an enrichment bring by new actors. This study considers that the object is mediator when it transforms an intention into conception and define the representation as a reference to propositions and characteristics derived from the future product.

Therefore, the object is considered as a mediator in interactions between involved actors. In order to take a decision, design actors exchange arguments based on objects.

(Jeantet, 1998) consider the intermediary object as tool to enhance cooperation between design actors. In fact, the work of(Grebici, Rieu, & Blanco, 2005) focused on the characterisation of intermediary objects and design parameters in order to facilitate the exchanges in design process. This study refers to(Lécaille, 2003) who defines different types of objects according to the space of collaboration. He describes the evolution of shared or exchanged design artefacts within the design space:

- The draft refers to the state of an artefact which is the proposal of an actor
- The exhibit is the state of an artefact to which a modality of argumentation is applied. The exhibit is used by actors to convince each other about an existence of a problem, or to present a solution in order to exchange opinions.
- The enabled trace state (Enabled) resulting from the approval of the other actors; The enabled trace is the state of an artefact to which a consent modality is applied.

According to Lecaille, the evolution of an artefact through the design spaces is not linear. (Grebici et al., 2005) considers Lecaille's approach and add the deliverable status. The deliverable is defined as an artefact subject to formal verification and validation procedures at the end of a design process, communicated to external actors in the organisation:

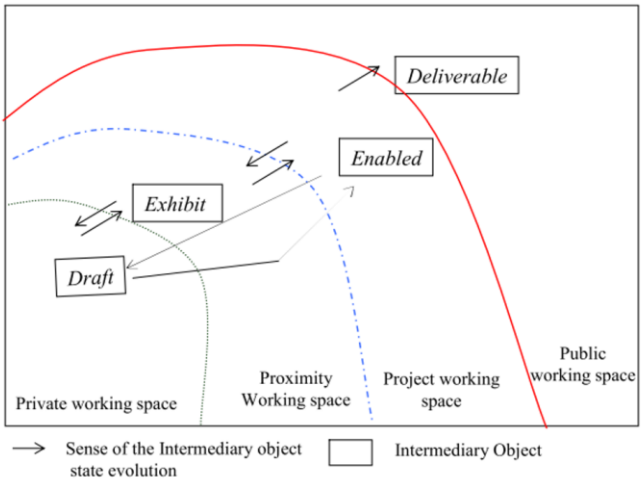


Figure 30. Theoretical model of the evolution of the maturity of an intermediary object during a design phase (Grebici et al., 2005)

Following this method, which consisted in identify and analyse the IO between design actors provide a more in-depth understanding of the design activity.

Vinck(Vinck, 2009) adds a dimension to the intermediary objects in the design process, through what he calls the equipment. This is necessary when the objects go beyond the boundaries of the team or department and acquire a public status. This concept will be discussed in the next paragraph.

2. Boundary object

The circulation of intermediary objects makes them shared between different areas of expertise during the design process. Different design actors collaborate within multi-skilled environment. If we consider the limits of the fields of expertise, these constitute boundaries and the objects that are produced and intended to serve as intermediary between these areas of expertise are referred to as the "frontier object". Here we come close to Star's concept of a boundary object in his famous article(Star, 1989). For Vinck, they are born in action and support interaction between designers. He distinguishes that intermediary objects can mediate, and frame action by their form and their materiality (Vinck, Jeantet, & Laureillard, 1996). The boundary object is an intermediary object that is flexible enough to be adapted to the specific needs of the different actors who use them and are robust enough to maintain a common identity(Star, 1989). In his work on heterogeneous problem solving, Star observes that despite the existence of considerable differences between scientists from different disciplines, they manage to cooperate in a very successful way. The author then describes boundary objects as objects that serve to provide a context shared between these actors. Four types of boundary objects are defined by(Winget, 2007) as follows: repositories, the ideal type boundary object, coincident boundaries and standardised forms.

1. Repositories consist of a set of objects classified and indexed in a standardised way, such as the library or the collection

2. The ideal type boundary object is a general model that abandons local or singular specificities a diagram or atlas, which does not comprehensively describe the details or specifics of any one locality

3. Coincident boundaries designating objects that share the same boundaries with different internal contents depending on the community using it

4. Standardised forms are those information objects developed to facilitate the communication and the reconciliation of various contents.

The study of Carlile(Carlile, 2004) describes the three characteristics that make an artefact a boundary object: syntactic, semantic, and pragmatic. According to the author, a boundary object must

- First, establish a syntax or shared language to allow actors to clarify their knowledge. In other words, develop a common vocabulary for the transfer of domain-specific knowledge.
- A boundary object must also provide actors with the necessary means to specify and learn their differences and dependencies on a boundary. Pragmatic ability allows actors to specify their needs, set common goals and transform them into domain-specific knowledge.
- Finally, a boundary object should facilitate the processes of knowledge transformation between actors. It should provide actors with a semantic ability to identify new knowledge and correctly transfer it to a specific domain. In case of a problem requiring collective resolution, the shared object or representation must provide the actors with the opportunity to negotiate, adjust, or modify it.

The concept of boundary object has been highlighted in different areas and adopted by different scientific fields. The study of Lee(Lee, 2007) proposes the concept of Boundary Negotiating Artefacts to describe the representations that are created and used during cooperation sessions. Actors who have potentially conflicting positions can share these objects as coordination support. Created artefacts are studied as tools of coordination, information support or mediation between different actors. They are considered in various situations as extensions of human memory.

3. Shared representations

In design activity, it is important that design actors externalise and communicate between each other. Various research studies highlight the creation of the common ground as a solution to improve the communication between different actors. We can define the concept of common ground by the representation of common knowledge between actors. Clark and Brennan (Clark, Herbert H., Brennan, 1991) assume that effective communication requires grounding activity. It actually enhances co-creation between design actors through the shared representation of a current design problem or design discussion.

The study of Visser (Visser, 2006) also underlines the role of creating a common ground during the co-designing activity. She states, "It *is then essential that designers, who each also have their personal perspective, establish a common ground*". Then, she explains that based on the common ground, design actors can efficiently create shared representations, which are the "*concern agreements, especially on the definition of tasks, states of the design, references of central notions, and weights of criteria and constraints*".

Many other studies were interested in the concept of shared representations and the role they play in facilitating the design task. For example, Conklin(Conklin, 2006) states that clarifying disagreements in work group can be assisted by shared displays. In other words, when ideas and concerns are mediated via shared display, it helps participants clarify the nature of their disagreement.

From a cognitive perspective, the studies of (Thi, 2013) and (Cassier, 2010) underline the importance of shared representations in the understanding of decisions and argumentation for the evaluation of solutions. In their study, (Boris & Whyte, 2009)explain that these shared representations in collaborative design are knowledge support. They belong to several domains and serve for coordination or as a mediator as well as a support for information.

Our research work studies the design objects and their uses in collaborative design. The importance of shared representations in the design process, especially their impact on the interactions between design actors. We will evaluate their effect on supporting collaborative design activity and to which extent these design objects leverage the end users in design task.

2. Research problem: the improvement of collaborative interactions based on Spatial Augmented Reality artefact

1. Collaborative design process as communication through design artefacts

Communication is a relationship built between two people who share knowledge, affinities, languages etc. It creates and transforms the common knowledge between the actors and their respective ones.

On one hand, the communication during the collaboration is characterised by a confrontation of different points of view: on the object, the knowledge or the project. It uses verbal argumentation and gestures, not necessarily design artefacts as a means of externalisation.

Schön (Schön, 1983) mentions the dichotomy between language and the action of drawing: "*the action of drawing and speech are parallel forms of conception, and both sets constitute the language of design*". Based on this study, Coyne (Coyne, Park, & Wiszniewski, 2002) confirms that a shared drawing device, visual contact (gaze direction), information sharing, and the use of a drawing board affects how designers work. Therefore, we can state that there are several channels for communication. Thus, communication channels can include speech, eyes contact, the gestural aspects and design artefacts (intermediary objects).

If a design team wants to perform a collaborative activity in a shared workspace there must be the execution of a certain number of actions: creation of intermediary objects, organization of existing intermediary objects, exploration of the space or of a set of intermediary objects.(Kuwana, Yana, Sakamoto, & Yuzo, 1996).

One of the main features of intermediary objects is to represent a local language. They form a cooperation space where the actors can build the product together. The goal of design activity is to realise a product or a service that meets a need. In order to achieve this goal, design actors collaborate on a range of sub-tasks involving multiple design representations and objects.

Perry and Sanderson(Perry & Sanderson, 1998), assume that design work is constructed through interactions between different actors. In addition, they consider that artefacts and design representations play a key role in the organisation of the design task.

In fact, (Rosenman & Gero, 1998)state that people operate in a socio-cultural environment, while objects are part of an artificial or techno-physical environment. All integrated into a socio-technical environment.

Collaboration around design objects can thus be an interaction between several actors, who can act or look at an object at the same time while virtually constructing an artefact. This type of interaction is different because when we look at IOs, we do not necessarily address a single actor, as in a situation of conversation. Therefore, the work on design artefacts seems to be more open.

Several studies in the literature agree that the design of complex products is done largely during the negotiation and argumentation phases between participants, through proposals, essays and evaluations(Bùdker, 2000) (C.M Eckert, Cross, & Johnson, 2000). Studying interactions between designers is therefore one of the main ways to understand the mechanisms of design. In addition, proposing and introducing good methods and tools of communication has a direct influence on the improvement of the design.

One of the main approaches to study design communication is to look at the links and boundaries between participants who communicate. According to their study, where they qualify design as the link that connect participants, (Finger, Konda, & Subrahmanian, 1995) argue that concurrent design must focus on how these connections among participants are created, maintained, and expanded.

Design communication is dealing not only with the interaction between the designers, but also with the interaction between the designer and his environment, i.e. how the designers act in a given situations. Different cognitive approaches attempt to understand how designers think and act(Stempfle & Badke-Schaub, 2002), or the communication strategies they follow(Gero & Mc Neill, 1998)(Maher & Tang, 2003)according to different contexts.

On the other hand, many studies on design communication focused on artefacts. There is now general agreement between the researchers on the crucial role of artefacts in design communication (Perry & Sanderson, 1998)(Claudia M. Eckert & Boujut, 2003). Schön (Schön, 1983) highlights the central role of artefacts in defining design as a reflective conversation with materials. There are multitudes of artefacts created and shared during design, such as sketches, technical representations, functional diagrams, or schedules. They are created and shared to represent constraints, forms, functions, materials, etc. Bucciarelli (Bucciarelli, 2002) defines artefacts as a basic way allowing designers to express and externalise their thoughts. However, they are also objects of interaction, providing designers with communicative resources(Robertson, 1996). They form a common ground between participants from different fields, to be aware of differences in interpretation and conflict, to achieve a shared understanding, to negotiate, and to decide. They are also objects that reify collective agreements(Bucciarelli, 1994).

2. Research questions

The study of human-to-human communication cannot be considered as a simple process of information transfer between interlocutors(Hisarciklilar, 2008). This study must look at the dialogical and evolving aspects of communication, in other words, how the interlocutors co-construct the meaning for communication.

In the case of collaborative design situations, the need for communication becomes crucial, due to the strong interdependence between the participants.

The actors make argumentative and dialogical exchanges, in order to elicit their specific points of view, to argue the design and to make collective decisions. The actors need to build connections between the different aspects that make up the design task, while offering the other actors ways of expressing mutual knowledge, in a logic of convergence to a decision in order to successfully complete the design task.

They also need to converge to a collective understanding of the design situation: its objectives, the artefacts that represent it, its evolution, etc. Thus, artefacts have an important role in communication between participants. They are not only means of expressing and externalising thoughts for the designer, but they are also objects of interaction, serving as a common basis between participants from different fields and backgrounds, which allow argumentative communication.

In face-to-face collaborative situations, language and gestures accompany graphic expression for a robust argumentative communication. The actors use the language to achieve a shared understanding of the graphical objects by reducing ambiguity.

Moreover, as design teams involve clients and end-users in the design loop today, these teams are increasingly using innovative technological tools that are often not familiar for the majority of participants. However, communication in the design phases requires adequate supports, especially around 3D representations.

Our research questions will concentrates on characterizing the improvement of collaborative interactions based on Spatial Augmented Reality artefact . The focus is on the effect that this technology has on interactions between different participants depending on their type. In addition, the question will be on the extent of spatial augmented reality tool can enhance communication between design actors. Then, we will study the effect of this technology through its mixed artefact on the involvement of clients (or end-users) in the collaborative design task.

We formulate our research questions as follow:

- **Research Question①: How the integration of spatial augmented reality platform influences the interactions occurred in collaborative design meetings?**

- **Research Question②: Does the use of spatial augmented reality prototype has an effect on external stakeholders' participation in collaborative design task?**

These questions will be investigated by the rate of participants' involvement of intermediary objects that we call artefacts during collaborative situation. Then we will measure the rate of involvement of artefacts in purpose of communication.

3. Checking the validity of research problem: Design a controlled study

This section aims at presenting how we check the validity of our research problem. Our research questions deal with the potential impact of new technologies as spatial augmented reality can have on collaborative interaction. Through this pilot study, we want to check if the use of SAR fosters the design task comparing to the conventional way of work. If it is the case, we assume that this innovative technology enhance the communication between design participants.

Firstly, the main driving motivation was to investigate the potential link between Spatial Augmented Reality and communication between design session participants. SAR is a form of augmented reality that is independent of the user's position, often relying on projection, but also video and holographic displays, to combine the digital and real world together. Therefore, we set a controlled study to mimic a real collaborative design activity(Giunta et al., 2019).

The technology used in this experiment was based on the developed platform by the SPARK consortium. This platform was developed to support designers, clients and end users during collaborative design sessions. The way SPARK supports the collaborative aspect is by providing a shared representation that all participants can see and collaborate on and which reacts to their edits in real time, allowing for feedback to be actioned instantaneously.

The main metrics we used for this study are the measurement of interaction intensity and the comparison of communication behaviour in different conditions. We will investigate whether there are significant differences in the number of interactions within the design meeting involving a SAR tool and a non-SAR set-up.

a. Describing the emulated collaborative design activity

The collaborative design activity to be emulated involves two participants: one playing the role of client and one representing the designer. The task is that the client shares the details for a target packaging to the designer so the latter can reproduce the same design elements through his digital interface.

The target model is shown hereafter. Only the client was allowed to see the model but could otherwise describe it in as much detail to the designer.

Figure 31. The study target model used only by Client

The task given to the participants was to replicate the target model on the shared representation (on the mixed prototype or on the PC screen). Participants were informed that the session would be over whenever the client felt confident that the shared representation was a satisfyingly accurate replica of the target model they held.

b. Experimental Setup

In this paragraph, we detail the experimental set-up and conditions and then explain how this study enables us to investigate the comparison of communication behaviour in different conditions.

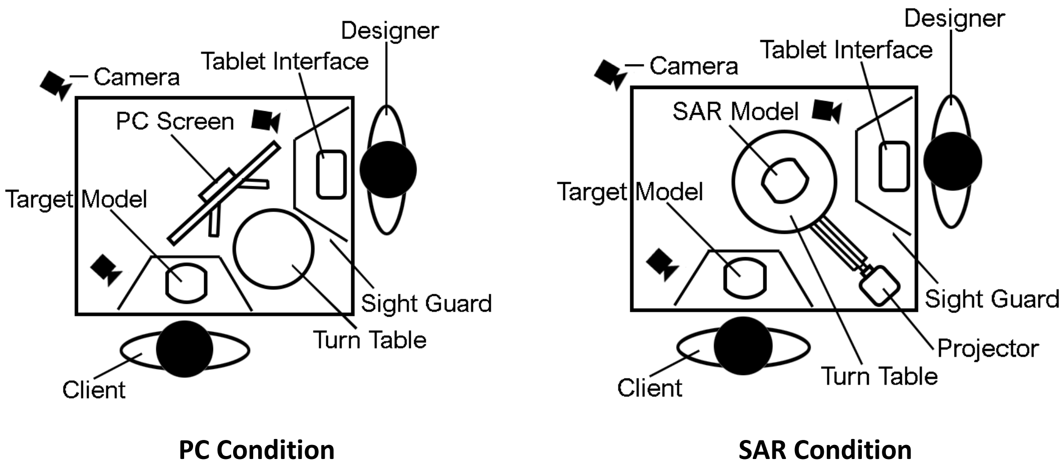


Figure 32. Schematics of Experimental Set-Up(Giunta et al., 2019)

The figure 32 above shows the two experimental set-ups for both the SAR (Right) and the traditional shared PC screen (Left), respectively.

Seven sessions were recorded involving fourteen participants recruited by our partner University of Bath. Participants were recruited from the Faculty of Mechanical Engineering and Faculty of Electrical Engineering. The participants playing the role of designer had experience with Computer Aided Design (CAD). The participants were all students in postgraduate or final year bachelors in order to guarantee the same level of competences. In order to post-process, the data gathered in this study, we set three cameras for each session.

The objective of the session was for the designer to accurately replicate the Target Model held by the client. To control the scenario further, the client was informed that they were not permitted to show the Target Model to the designer and the designer was informed that they were not permitted to show the interface of the tablet for editing the shared design representation.

The SAR system could be seen by both participants and project graphical elements onto a shared physical model fixed to the top of a turntable. This turntable was available to be manipulated by both participants.

The experiment had two conditions: PC and SAR the difference between the two sessions was how the shared representation was displayed. In one condition on the PC screen and in the other using the SAR mixed prototype fixed in middle of table. A touch interface was used by the designer. This modifies the shared representation in both the SAR and PC set-ups. All the necessary assets to replicate the design held by the client were here as well as some additional useless assets. The interface was not changed across the different session types. The designer was provided in both conditions with this interface.

Figure 33. The interface the designer was provided with in both conditions

c. *Data Analysis and results*

In order to understand the design communication that occurs in collaborative sessions, different typologies of interactions between participants need to be observed and analysed. The interaction centric framework (chapter1 on Part II) is based on the capture of interactions through different types of artefacts: tangible prototypes, digital, mixed and ephemeral for gestures performed by participants.

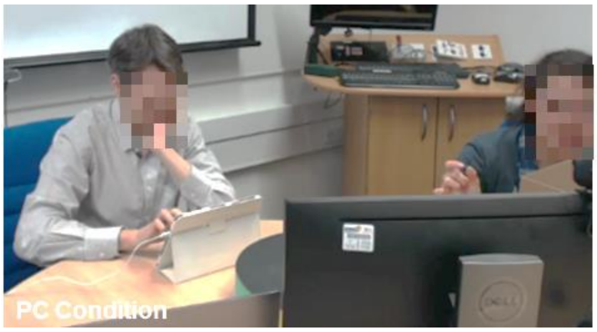


Figure 34. Design meeting with PC condition. The shared object is displayed on monitor

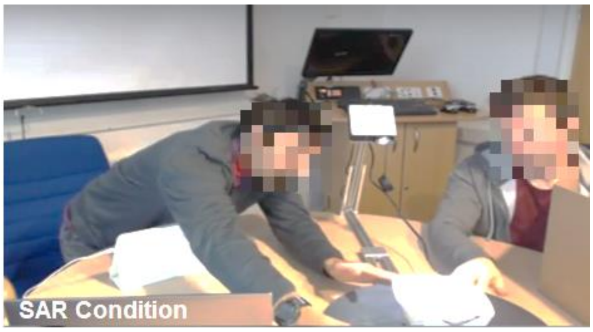


Figure 35. Design meeting with SAR platform. Participants share the mixed prototype

The analysis of the participants' interactions provides understanding on how participants share ideas and get closer to the target packaging result.

Analysing the participation of each session actors can be drawn in the following graph:

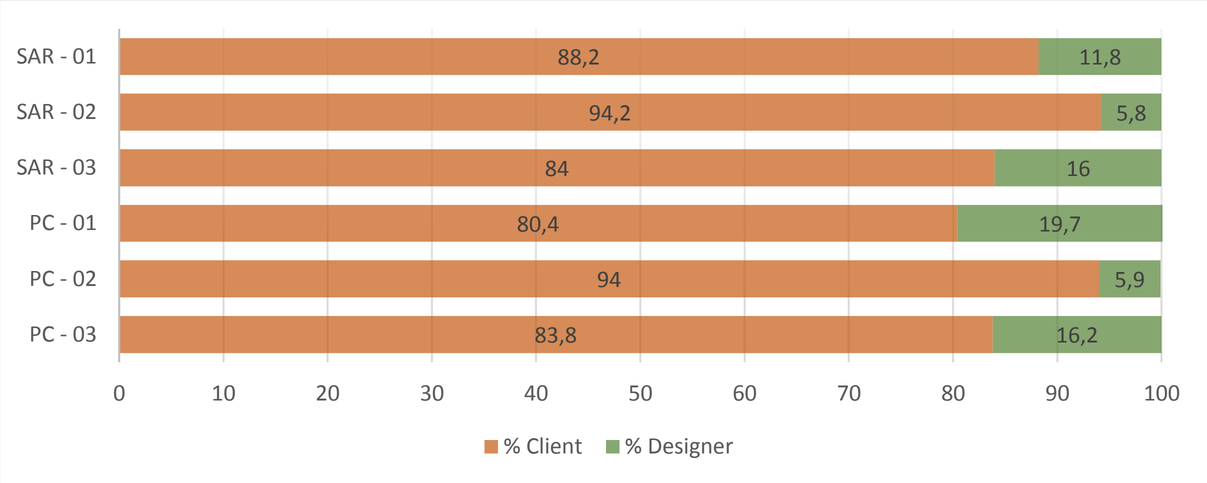


Figure 36. Actors' participation of each session

Of the seven, the SAR model supported four sessions and three used the 3D digital PC representation (Figure 34 and 35). In six session participants manage to achieve the final target. Only one couple of participants failed to replicate the provided model. Unsurprisingly in both technologies cases, the client initiated most of the interactions, which given the nature of the task seems very understandable.

However, when analysing the types of interactions we found some interesting results: In the SAR sessions the participants relied more on the shared representation to communicate with one another.

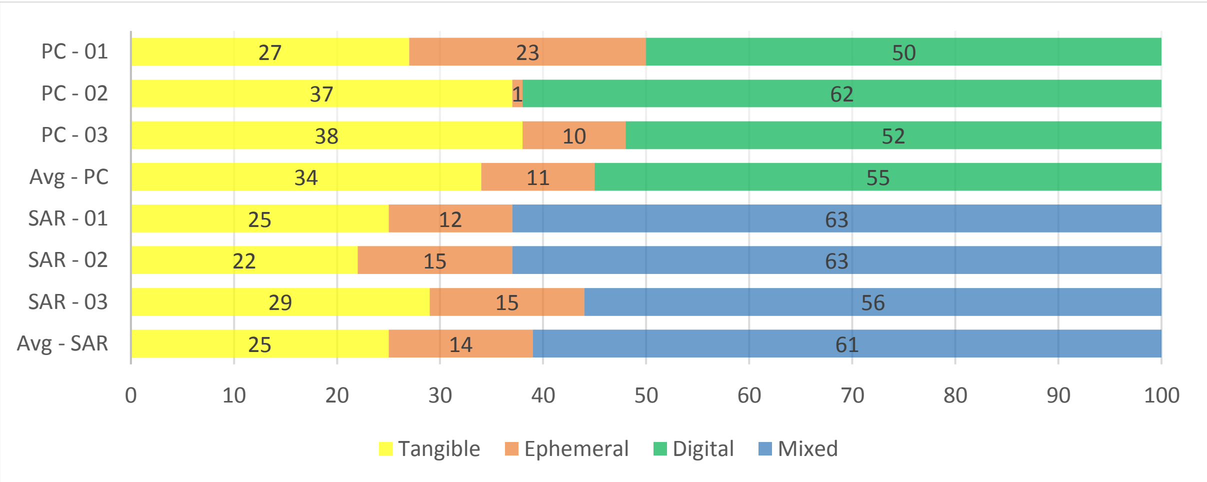


Figure 37. Distribution of artefacts used in the seven sessions

In addition, according to the established state of the art, gestures are good indicator of communication between design participants. Graph of figure 37 shows as a result that in average of both conditions, participants tend to gesture more when they collaborate around the SAR tool.

In addition to interaction analysis, we also consider a second parameter, which is a comparison of the time taken to complete the design task for each condition. We define the starting point of session when participants start discussing the design task. The end of the session is defined when the client assumes that the result is close to the target representation. The following table 1 regroup the time taken to perform the design task for each session and the mean parameter for each session category:

	SAR				PC		
Session number	1	2	3	4	1	2	3
Time taken	09:52	23:41	24:12	16:39	26:38	17:15	28:03
Mean	17:51				23:59		
Median	18:56				26:38		

Table 1. Time Taken for Each Session and Condition

In the following figure 38, we present the mean time of each condition:

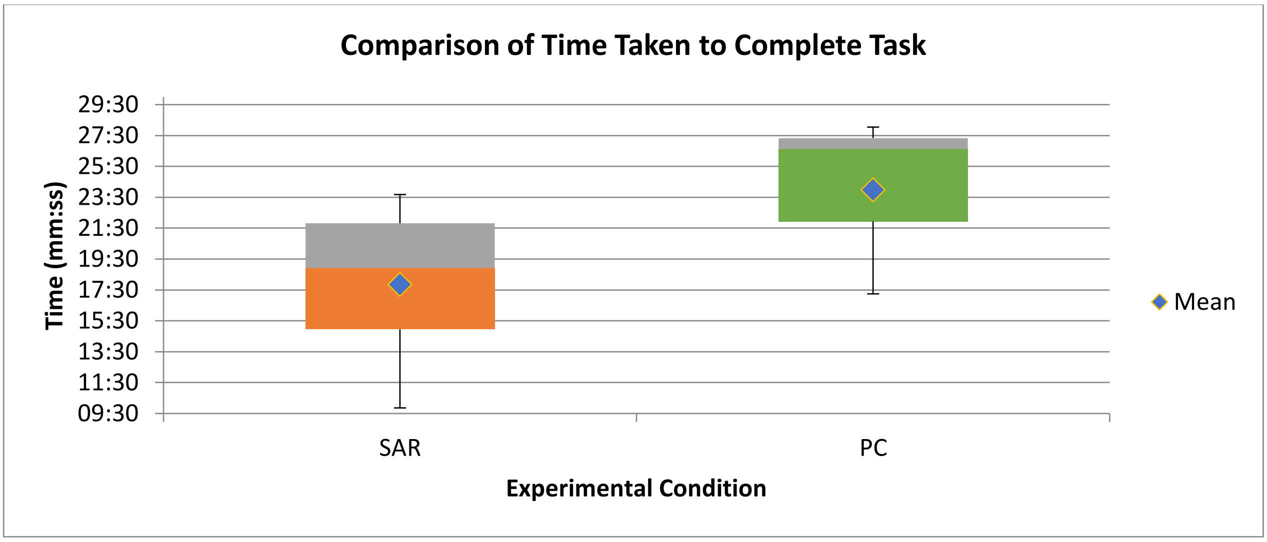


Figure 38. Comparison of Time Taken to Complete Task for both conditions(Giunta et al., 2019)

Figure 38 shows that the mean time taken to accomplish the design task for SAR condition sessions was lower than when participants manipulate the standard PC condition sessions by 6 minutes and 8 seconds. It shows that the SAR sessions seem to allow the participants to more quickly convey information.

The results of the sessions' analysis tend to claim that design meetings supported by the SAR tool facilitate the communication of ideas and exchanges between design participants. Since we set our study on a controlled task, the condition to achieve the design task was to communicate efficiently. According to the displayed results, the sessions supported by the SAR seems to reduce the time to complete the task and to improve communication between participants.

In conclusion, this study shows positive feedbacks in assuming that the SAR tool and its mixed prototype seem to support communication between design participants. The mean time of SAR sessions was clearly shorter than the standard sessions with PC. The percentage of interaction between participants favourites the SAR shared representation comparing to the standard PC screen.

In order to improve these primary results, we need a further work around the SAR platform. In the following chapters of part III, we will set multiple observations focusing on evaluating the use of SAR in collaborative design sessions during the creative review stage in real industrial context. These analyses can allow us to properly answer our research questions.

CONCLUSION OF PART I

Part I is dedicated first to review existing research studies concerned with collaborative design approach and secondly to present our research work context.

The first chapter based on literature studies allows us to draw definitions of design process in general. Then, product design process and collaborative design process in industrial context. We consider here the design process as a collective and collaborative process involving technical and social knowledge.

The collaborative and social aspects come from involving external and internal stakeholders in design activity. According to the established state of the art, it enriches the design process but may also involve some problems of misunderstanding of users' needs and requirements.

In the technical aspect, we are concerned with the tools involved in the design process. We have presented a literature review listing existing ICT tools based on various technologies and set criteria of efficient ICT tool for communication in collaboration. Based on the identified criteria, we assume that Spatial Augmented Reality is a suitable technology to support interactions in collaborative design context.

Therefore, the second chapter is dedicated to present our research tool: SPARK platform which is an SAR based platform developed within the European SPARK project (H2020). Our assumption in this project is that the proposed platform is an efficient and adequate tool to support collaboration during design meetings involving external stakeholders. The SPARK platform will enable the latter to enhance their participation and to express their ideas in design activity. We detail the hardware and software architecture of the platform. We present the equipment and devices used to set up the SPARK room and then we detail the software components: visualisation, tracking, interactions and Information System modules. Finally, we illustrate the presented architectures with an example of how to run a collaborative design session supported by the SPARK platform going for the set-up of the hardware materials to the software adjustments. Then finally, how the different components are set together to ensure a collaborative session.

The last chapter is concentrates on the research problem and questions of our work. We elaborate an exhaustive state of the art around design artefacts and the role they play in communication and supporting collaborative interactions. The research problem is presented as how interactions in collaborative design can be improved through design artefacts with a special focus on the role of Spatial Augmented Reality artefact. We then elaborate our research questions as follow:

First Research Question: How the integration of spatial augmented reality platform influences the interactions occurred in collaborative design meetings?

Second Research Question: Does the use of spatial augmented reality prototype has an effect on external stakeholders' participation in collaborative design task?

Finally, the last section is dedicated to a pilot study we conduct in order to test the legibility of our research problem. The idea behind was testing in laboratory conditions and with design students the role of Spatial Augmented reality artefact in supporting communication between different design participants. The elaborated results were encouraging to boost the continuity of our research work for real industrial tests.

PART II:

RESEARCH APPROACH: DESIGN OBSERVATION APPROACH

Abstract

The second part of the manuscript is dedicated to detail our research approach. We adopted the design observation method for this research.

The first chapter presents the methodological framework and the methodological tool. We choose to observe our collaborative design activities based on protocol analysis method. We have applied this approach on 6 different cases . We designed our situations in order to control the variables of the observations. Therefore, we will be able to gather comparable data from these observations. The next step was concerned on how we collect our observations' data and how to process it through the chosen analysis framework.

Chapter 2 is dedicated to firstly present our industrial partner, the design agency. Then, we define each of the case studies through the presentation of participants involved, products used and the technological environment of the session.

CHAPTER I: Methodological framework and tool

Abstract

Based on an early study of Ericsson and Simon (Ericsson and Simon, 1993) who provide strong evidence of the potential validity of protocol analysis and provide specific methodological recommendations for the use of protocol analysis. We potentially can consider protocol analysis as a related research methodology that can be adopted to test our assumption.

Cross et al. (1996) recommends the use of a design protocol analysis methodology to address research problems related to the behaviour, cognition of design activities. We can assume that design observation study is more adapted to our research context.

We present a comprehensive review of different available literature on speech and gestures analysis in order to determine which one is more adapted to our research context and goals. Then we present how an observation can be designed, carried out, evaluated, and the outcomes can be analysed.

First, we describe our design situation and identify the environmental variables in order to perform similar observation in vivo and in vitro. By taking these parameters as a reference, laboratory observations are designed to be as similar as possible to real design observation in design partner premises. The design observation process is described and expanded.

The second part is dedicated to data management going from data capture to post processing procedure. Finally, we present the process of our taxonomy development. We highlight our interest on artefact centric interactions. We build an analysis framework around interactions performed on artefacts and based on gestures. The last step was the presentation of validation of taxonomy procedure.

1. Methodological framework

A. Protocol analysis method:

1. Definition of protocol analysis

Newell defined the protocol as "a piece of record of the time path of behaviours"(Newell, 1966). We can adopt the general definition of a protocol as being a capture of multimodal data recorded from a human activity in order to carry out future analysis from one or different points of view.

The analysis of these gathered data is the foundation of the "protocol analysis" method (Ericsson and Simon, 1993). Protocol analysis is considered as an empirical and observational research method whose aim is "to understand cognitive mechanisms and processes that produce relationships between stimulus and responses that appear during a human activity." Such understanding can be achieved using a protocol that includes mainly people's verbalisations, but also people's behaviour like "movements or physical manipulations of stimulus material, direction of the subject's gaze". However, verbal and audio visual reports remain the basic material of the protocol analysis method.

In his review, Afflerbach(Pearson, Barr, Kamil, Michael, & Mosenthal, 2016)confirm that the work of Ericsson and Simon continues to influence the conceptualisation and use of protocol analysis related to information processing and cognition, and the authors present a compelling case for protocol analysis as a methodology with flexibility of application that can help to describe the extent of perception. Ericsson and Simon provide strong evidence of the prospective validity of protocol analysis, and they proffered specific methodological recommendations for using protocol analysis.

2. Design protocol analysis

Based on the cited references above, protocol analysis is considered as rigorous research method relevant in many domains. This method has been used extensively to analyse and understand design. We can define the design protocol analysis as the application of the protocol analysis method (Ericsson and Simon, 1993) to analyse design activity and understand the thought process of designers.

Among the first studies, Cross et al. (1996) recommend the use of the methodology of design protocol analysis. They set the well-known "Delft protocol" which is an experiment held during a workshop at Delft university. During this workshop, they present the design protocol analysis approach as they define it for the first time. It consists on transcribing the utterances among three designers. These analysed statements can be composed by complete sentences or incomplete thoughts.

This approach aims specifically to understand how designers think and behave individually or collectively while they are designing(Ben Guefrache, Masclet, Prudhomme, Cascini, & O'Hare, 2018). The Delft workshop initiates that the design protocol can have different analyses. Setting one design experiment protocol can answer many research objectives such as understanding the way designers articulate their argumentation, exchange and build their solutions with other participants in design meetings.

The design protocol consists of the recording of what occurring during the design session: the designers' speech, behaviours and any material created during the session. The data collection is based on video capture as the most reliable technique allowing the researchers to operational posteriori analysis(Mondada, 2006). Through the video corpus gathered during design meetings, the researchers have access to the audio information: the participants' speech plus visual information such as the interactions, behaviours and all the produced elements throughout the design session.

They can listen to the verbal content many times and review the content of actions and exchanges as much as they need.

a. Speech interaction analysis methodology

Most of the reviews and books dealing with design protocol studies are interested in analysing the spoken interactions (Mcdonnell & Lloyd, 2010) These behavioural studies observe designers when they talk to each other in collaborative design sessions (conversational protocols)(Niccolo Becattini et al., 2017), or when a designer express his thoughts or ideas (think aloud individual protocols)(Jiang & Yen, 2009). Speech information are composed of utterances, which contain information related to the assessment and performance of actions, or, as called by Austin, “things that people do with words”(Austin, 1962). Hay (Hay et al., 2017)confirms that design protocol analysis mainly aims at capturing relevant cognitive processes in order to characterise the design activity. For these studies focused on verbal interactions, the methodological process follows the same steps: first, researchers define their analysis framework in order to characterise what occurs during a design session. Once they record the spoken exchanges between design participants, they transcript the corpus. Then the corpus is segmented and classified according to the analysis framework, which allows the researchers to execute analysis and draw their conclusions.

b. Gestural interaction analysis methodology

Compared to verbal interactions, gestures have been least analysed in collaborative design. The International Society for Gesture Studies states that gesture studies are concerned with how people use their hands and other parts of their body for communicative purposes. They also define gestures as visible bodily action that plays a role in explicit communication.(“Gestures Studies,” n.d.)

Gestures in design have been studied for several purposes: creativity, cognitive process, human-machine interfaces development. However, it is most generally supposed to play a role in communication. These different perspectives lead to diverse categorisation of gesture interactions. Most of the studies refer to the gesture specialist David McNeill (Mcneill, 1994) who identifies four categories of gesture: iconic, metaphoric, deictic (pointing), and beat gestures.

McNeill has confirmed that gestures are fundamentally different in form compared to speech despite the strong connection that gestures have with spoken interactions. McNeill assumes that gestures include some dimensions of thought. His research findings have implications on the role of gesture in designing: first on the role gestures play in design thinking and the role it plays in design collaboration as considered more than simple communication vehicle (Visser & Maher, 2011).

In the field of cognitive sciences Visser characterized the relationship between function and form of gesture in design collaboration meetings through a proposal of interactions modalities analysis(Visser, 2010). Thanks to this study, functions of gestures can be classified between interactive function or other. The interactive gestures are used to manage interactions between different participants in a collaborative design meeting. Other gestures are used to generate and evaluate design proposals. It also can play a role in computer-supported design environments, allowing designers to transfer their ideas into a digital model(Davis, 2016).

In the field of engineering design, the early studies of Tang and Minneman (Tang & Minneman, 1990)and Bekker et al. (Bekker, Olson, & Olson, 1995) were interested in analysing the gestures of a small design groups. Following these researchers, analysing the gestures can enable designers to design more adapted design tools. For example, the results of Tang and Minneman study were used to design and develop VideoDraw, a shared drawing tool.

The study of (Cash & Maier, 2016) focused in the many roles that gestures play in the communication of design concept. They add a target categorisation in the coding scheme: when the focus of the participant is in his activity: it is a reflective gesture -toward himself or it is a directed gesture towards one or more participants. This research also highlights how designers discuss, investigate, and virtually prototype ideas with their hands and how gestural sequences are used to support kinaesthetic thinking.

We can also cite the study of (Davis, 2016)who focused on early stages of the design process, and recognise only iconic and metaphoric as gestures categories. She focuses on the important role that metaphoric gesticulations play support communication and the importance of gesture in the ideation process in early stage of design activity. She qualifies an important role of gesture in shaping, forming and developing ideas.

The study of (Cash & Snider, 2014)describes the gestures with two elements: the type and the target which is the interest and focus object of the participant. They state that gestures play the role of design concepts; participants also involve gestures repetition in their discussion sequences in order to build a shared understanding.

All the cited researchers stress the communicative role of gestures in collaborative design meetings. The highlighted function of communication motivate our work to focus on gesture tracking within design participants in order to evaluate the evolution of communicative gestures in different design environment (with and without the implication of technologies).

In addition to the communication dimension of gestures, other studies such as (Visser, 2010) highlights that some information of what is communicated through gestures in design interactions does not exist prior to the start of the gesture; it is created while gesturing. Eris et al. (2014) whose work is in design sketching context, confirms that gestures are also a kinaesthetic thinking medium as the participant explains and debates through the physical activity. Design practitioners can also formulate and communicate through the gestures and this why many studies consider gestures as design concepts. Again, the cited studies stress the importance of gestures in understanding design activity.

Most of the cited studies use to the traditional methodology of protocol analysis: capturing videos and audio data. The data are gathered then analysed in a post-processing phase allowing researchers to have a detailed and deep treatment to finally draw conclusions.

To sum up this part, design protocol analysis is a framework for the analysis of design activities. Researchers realise it through the following steps:

- Define the scientific aim of the research work and state the hypothesis and/or research objective;
- define the analysis framework;
- establish the observation conditions (in vitro/in vivo)
- Gather the visual and audio data following the observation protocol;
- Transcription of verbal data;
- Processing the gathered data towards qualitative or quantitative results;
- Analyse and draw conclusions with regard to the predefined research goal and research question. At this level, often we have a re-form of our conceptual framework and an evolution thanks to the analysis work that explore new features may be missed during the first proposal.

Finally, the studies presented above assume that protocol analysis is a well-established and powerful method for having access to results about design activity and design participant behaviours.

B. observation protocol:

As presented above, the first step of conducting an observation design protocol is to state hypothesis or expected results to be tagged during the observation. Through these elements will try to answer the research questions. Once the scientific research goal is fixed, researchers have to define the observation conditions: discuss the design phase and task with designers. They recruit end-users to participate in the sessions. These end-users have potential interest in the design task or design product and present interesting user profile for the designers. Finally, choosing the adequate material, tools and potential human resources (i.e. observers) to be involved in the session. When all these steps are valid, observations can be conducted and session will be recorded with videos cameras and microphones.

1. Context of research work

In our research work, the aim was to evaluate how the integration of a spatial augmented reality platform influences the interactions that occurs in collaborative design meetings involving end-users or clients. The process was then to conduct observations in the real work environment of the designers with their clients i.e., in the design agency premises. Once we build a comprehensive understanding of how usual design meetings are set using which tools and materials, we were then able to turn observations to our lab using the first versions of Spatial Augmented reality platform. Therefore, we will later be capable of evaluating if the SAR technology has any impact on collaborative design interactions.

Then our research work has been conducted in two different environments: in vitro and in vivo. Our objective was to reproduce as much as possible the same design environment as the one of our partner's premises in our lab. The goal was limiting the variation of work conditions for designers: Provide the necessary materials, digital and physical tools and equipment. We were also concerned about choosing the right end-users profiles to conduct the session. To achieve the cited aim, we start by identification of variables that may change and influence the design observations set.

2. Design of the Observation: Identifications of the main variables

Our research work aim is to test the impact of integration of spatial augmented reality platform on collaborative design meetings. IN addition to observation of designers' traditional way of work, we also invite the design team in our lab to test SAR platform, after each new release. Then we can ask for feedbacks in order to improve next versions.

During these platform trials, we conducted several observations of the design practice involving recruited end-users. In order to ensure the validity between the two environments (in lab and in design agency premises) we tried our best to cover all the requirements related to the design situation main elements in the usual work environment and replicate them when we design observation in our lab.

The design of the observation is discussed under three sub-sections: Observation Framework, Description of the Design Situation and Observation Process.

a. Observation Framework

In order to correctly answer the above-mentioned research questions, ideally, what we try to set in the observations the same configuration (the same participants, context, duration, materials used and so on in both observation environment), so that we can get the desired outcome.

Obviously, we can not completely achieve this goal, where the clients of the design company are not available to move to Grenoble Lab. Therefore, we were obliged to run the observations with locally recruited end-users.

Therefore, we call what we want to measure dependent variables: in each technology variations we need to evaluate the impact of technology used on : number of interactions between participants involving artefacts, the type of interactions (which actor initiate which type of interaction) and finally the typology of modality involved. We also define the dependent variable we want to test in each observation as the technology's impact on the interaction intensity between the design team.

By reproducing the controlled environment as faithfully as possible: number of participants, participants profiles, the nature of design task, the physical settings.. We will ensure that we can observe and measure the impact of the technology used (independent variable) on the interactions between participants during the session.

Thus, to control these variables, we try to create two configurations that are as similar as we can possibly make them. If we can ensure that they are comparable, then we can provide both observational groups with the same design task and products. Thereafter, we can analyse the outcomes of the groups and compare the findings depending on the variation of our dependent variables.

The rationale behind the configuration is then the following: there are two groups that are as similar as possible immersed in a controlled design environment and provided with different design tools; they manipulate artefacts (external representations) are the observable of the study.

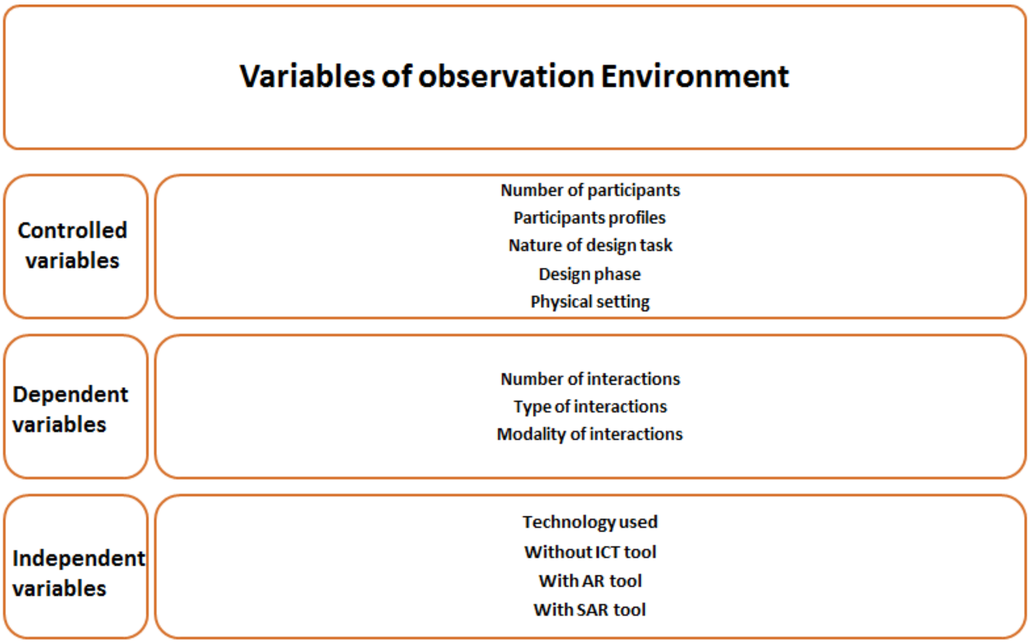


Figure 39.Independents and dependents variables of design observation

The two observations groups are immersed in the same environment; our assumption is that the differences in the findings between these two groups result from using or not the Spatial Augmented reality tool.

In order to ensure the comparability of findings, the designer who is in charge of manipulating the SAR platform has to be trained with the tool and methods that he will use during the meeting. A preliminary training step (Step 1) is hence required. In addition, before running the meeting, participants are informed about the observation procedure, duration, task and introduced to the design team.

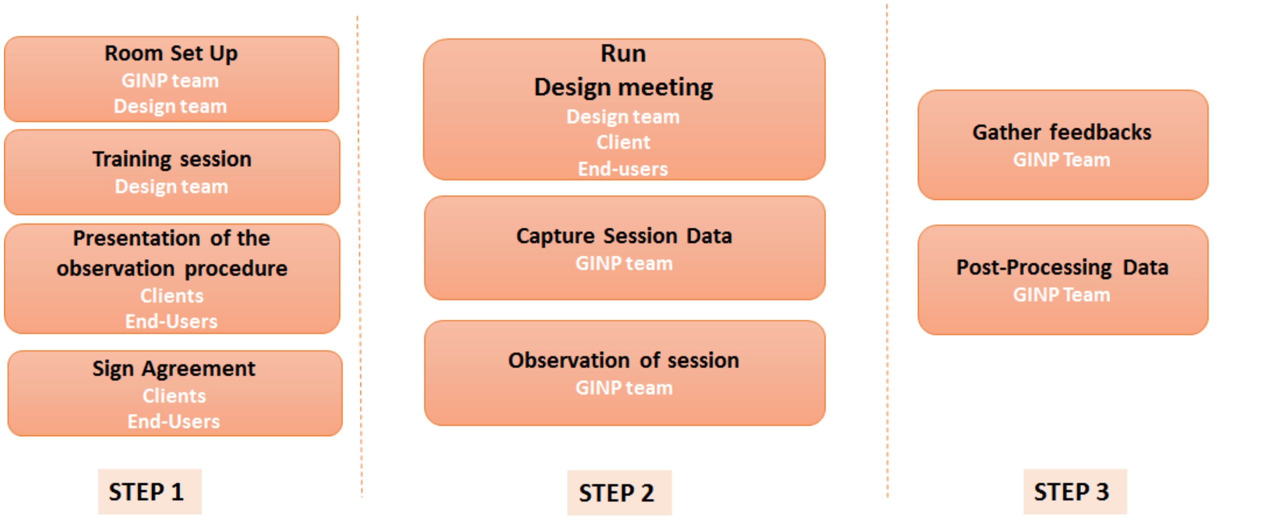


Figure 40. Detailed framework of the observation

b. The Design Situation

Following the synchronous collaborative situation model proposed by Prudhomme et al. (Prudhomme, Pourroy, & Lund, 2007)the design situation consists of four main elements: a design task, a design object or product, actors and environment. The design task is the aim of the design session and the context of the accomplished design work. The design object, or the product, is the entity on which the design actors work. The design actors are the involved participants of the design process. Finally, the environment element is described by the design agency, the available technical means and the project organization.

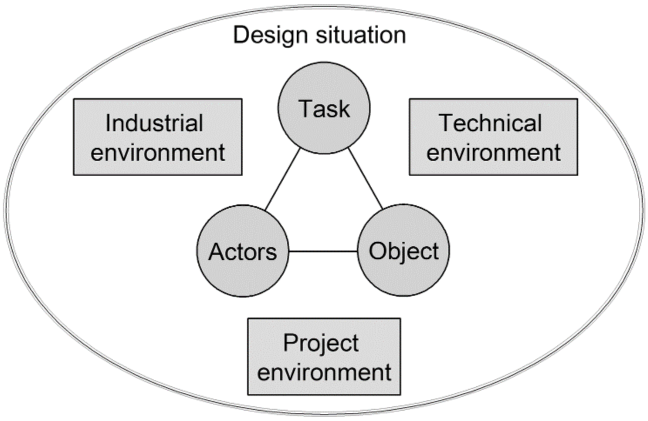


Figure 41. Synchronous collaborative situation model (Prudhomme et al., 2007)

- **Object:**

The industrial product to be worked on. The products involved in our collaborative design sessions were chosen from a range of innovative projects led by our industrial partner.

- **Task:**

We define the task as the design exercise to be accomplished by designers and other participants during the design meeting. The aim is to properly achieve the design task with consideration to the end-users or clients' requirements, suggestions and opinions. The task strongly depends on the design phase of the project this is why we chose industrial projects that had a comparable level of maturity to each other. The tasks should be completed within a 45-90 minutes range for each session.

- **Actors:**

The design actors are the subjects who participate in the observation. As we involve multiple participants in collaborative sessions, we tried to select their profile based on various parameters. We can cite background, age and gender. The participants' profiles also depend on the role they are playing: we involved designers, managers, creative directors, clients or end-users.

In each session, we agree with our industrial partner to designate a leader according to his previous experience. His role is to manage the session and ensure that the tasks are performed in time. The same manager was assigned to all collaborative sessions.

- **Environment**:

The environment is prepared either by the design agency or by the lab researchers. The most important elements that define the design environment are the site where the sessions will be held, the provided technology and/or tools: physical mock-ups of products, digital tools.

Our observations were held in two different locations. The next figures 42 & 43 display the observation room plans, the disposition of the participants and the equipment available (TV, whiteboard, heavy materials...)

➢ In lab Observation environment:

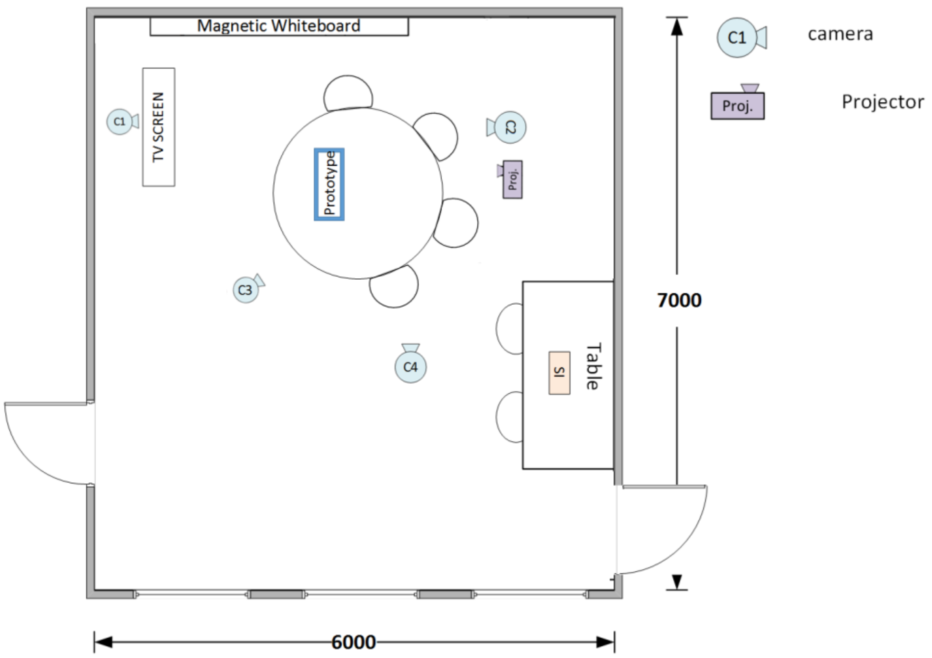


Figure 42. Grenoble INP lab observation room layout

➢ In companies Observation environment:

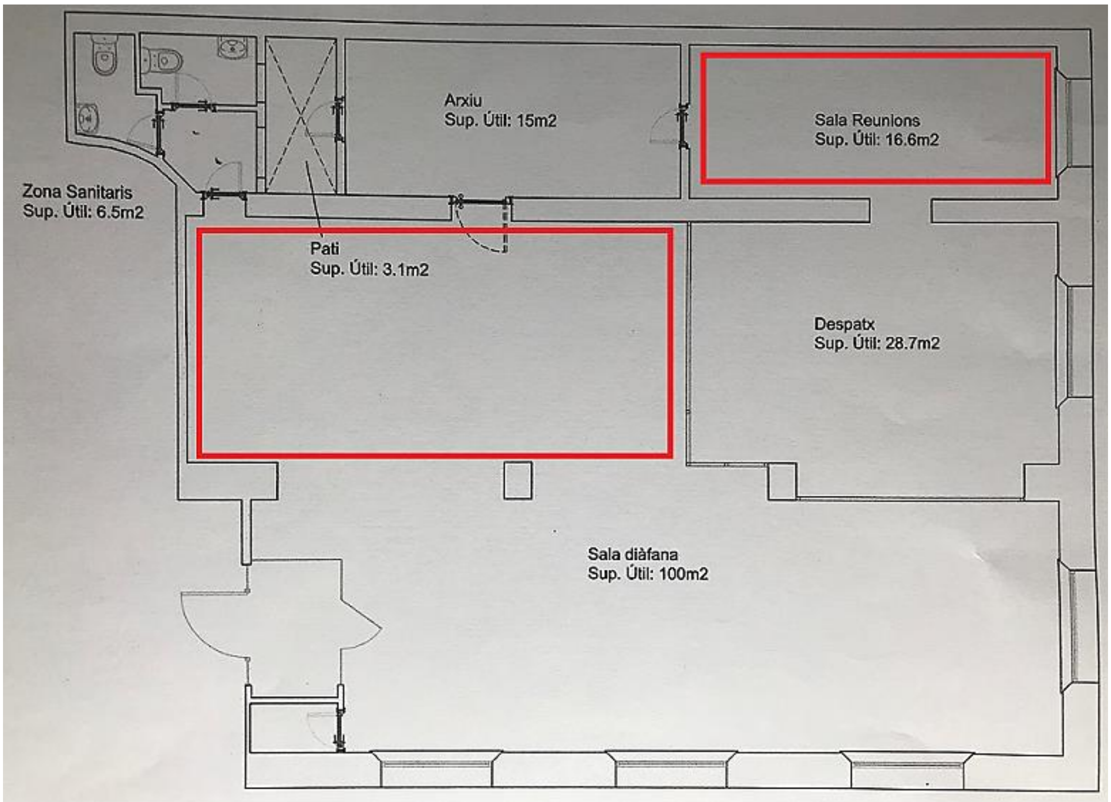


Figure 43. Design Agency observation room layout

The preparation of observational environment includes the materials to be supplied to the participants such as whiteboard, paper, pen, chair, laptop, TV screen, SAR platform etc. and their distribution plan. Participants are also allowed to use the Internet during the meeting. Preparation also includes the set-up of the video cameras, microphones in order to gather all the sessions' data.

c. *Observation process*

- At Grenoble INP GSCOP lab:

In this section, we will describe the observation process in our lab. Two types of observation sessions were run in the lab:

- collaborative design sessions with standard digital tool
- Collaborative sessions supported by the Spatial Augmented reality tool (SPARK platform).

In both cases we aim to compare the impact of the SAR technology on design interactions. Therefore, we need to record a creative design session where designers and end-users are working together through (or not) virtual prototypes (as a 3D representation) or physical prototypes (as a mock up for example). Indeed, here is the description of the observation's progress:

1. session Preparation

GINP team set up the observation equipment

Ask end-users and designers to wear lapel microphone

Inform participants of the protocol and ask them to sign the consent to participate. (see Appendix A)

Equipment used: 4 cameras + Tripods, Microphone, Lapel microphone for each participant and A Tricaster, which synchronizes the videos, A Tascam that synchronizes the recorded audio.

2. Run the session

The meeting will take place and be recorded.

During the sessions the observing team will be around the participants without being so intrusive.

3. Pack the material
4. Post process and storage of gathered data

Table 2. Lab Observation - Collaborative design sessions with standard digital tool

1. Pre-session

GINP team set up the observation equipment: the software and hardware of SPARK platform

Ask end-users and designers to wear lapel microphone

Inform participants of the protocol and ask them to sign the consent to participate (see Appendix A).

Equipment used: 4 cameras + Tripods, Microphone, Lapel microphone for each participant and A Tricaster which synchronizes the videos, A Tascam which synchronizes the recorded audio.

2. Training the designers

In order to familiarise the designers with the new version of SPARK platform that will be used during the session. A training session is organised and designers try a similar design task using the new features of the SPARK platform.

3. Run the session

The meeting will take place and be recorded.

During the sessions the observing team will be around the participants without being so intrusive.

4. Pack the material
5. Post process and storage of gathered data

Table 3.Lab Observation - Collaborative design sessions supported by the SPARK platform

1. Pre-session

Design team set up the observation equipment: physical mock-ups, pen, papers, drawings

Ask end-users and designers to wear lapel microphone

Inform participants of the protocol and ask them to sign the consent to participate. (see Appendix A)

Recording equipment set by GINP team: 4 cameras + Tripods, Microphone, Lapel microphone for each participant and a Tricaster Mini[1], which synchronizes the videos, A Tascam[2] DR-680 MkII that synchronizes the recorded audio.

2. Run the session

The meeting will take place and be recorded.

During the sessions the observing team will be around the participants without being so intrusive.

3. Pack the material
4. Post process and storage of gathered data (GINP team)

[1] The TriCaster is a compact, all-in-one multimedia solution that allow the stream and record live productions. It includes eight inputs which allow easy switch between four HDMI video sources or eight NDI video sources, mix audio, add graphics and titles, and add advanced effects such as virtual sets and transitions animated.

[2] Tascam: Portable multitrack recording: live recordings, It can record up to 8 tracks on SD card

Table 4. Observation in design agency premises - Collaborative design sessions with standard digital tool

1. Pre-session

GINP team set up the observation equipment: the software and hardware of SPARK platform

Ask end-users and designers to wear lapel microphone

Inform participants of the protocol and ask them to sign the consent to participate (see Appendix A).

Equipment used: 4 cameras + Tripods, Microphone, Lapel microphone for each participant and A Tricaster, which synchronizes the videos, A Tascam, which synchronizes the recorded audio.

2. Training the designers

In order to familiarise the designers with the new version of the SPARK platform that will be used during the session. A training session is organised and designers try a similar design task using the new features of the SPARK platform.

3. Run the session

The meeting will take place and be recorded.

During the sessions the observing team will be around the participants without being so intrusive.

4. Pack the material
5. Post process and storage of gathered data (GINP team)

Table 5. Observation in design agency - Collaborative design sessions supported by the SPARK platform

2. Data management

In the previous section, we present the different steps of the observation framework:

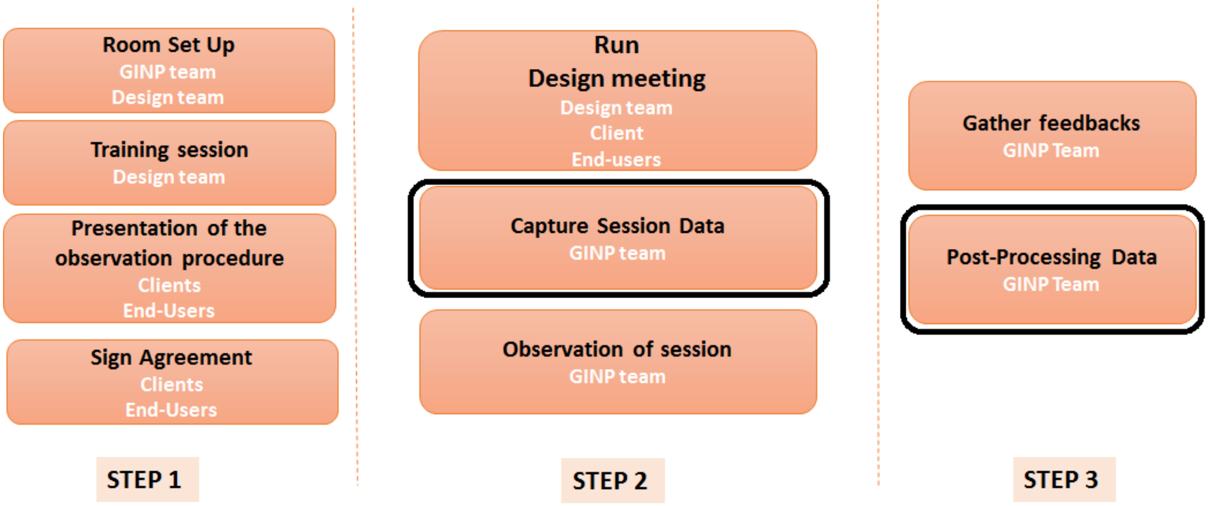


Figure 44. Detailed framework of the observation

In this second section, we will focus on the data management task: we will detail the steps of session's data capture and then the post-processing phase.

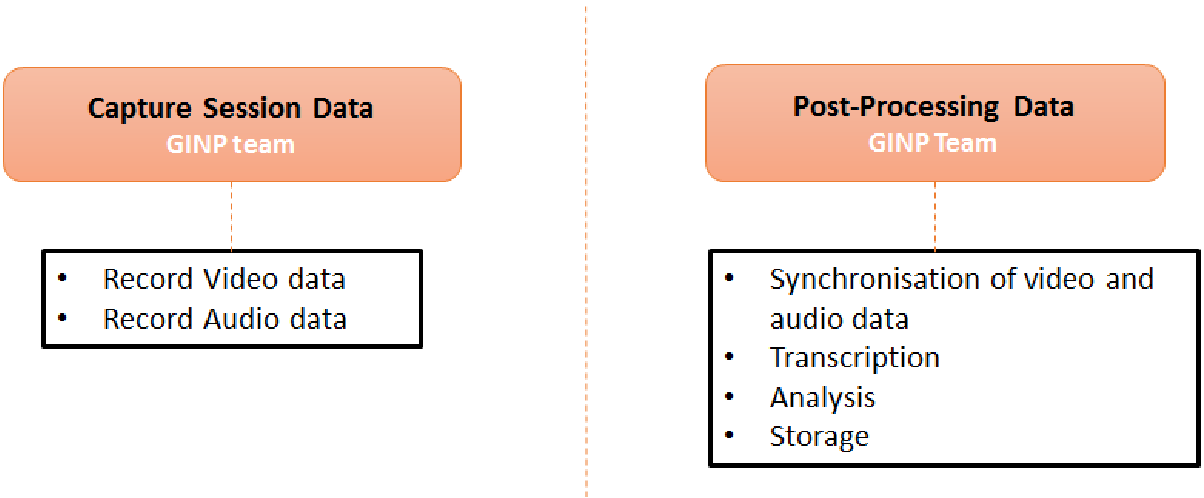


Figure 45. Detailed step of Data Management

A. Data Capture

In order to cover all the required aspects for the capture phase, we need to answer two main questions:

- What we need to capture in our observation?
- How to properly capture the intended data?

To answer the first question, we need to gather all information and record all the design activities involved during the session. We are not interested in capturing the pre and post-session. The design meeting is audio and video recorded. First, our video recording must cover the participants, all the input documents or materials. Then, all the interactions occurring between different designs participants when they realise the asked design task. All type of artefacts involved and produced during the meeting. In addition, we need all the gesticulations occurring between participants.

How to properly capture the desired data?

We assume that recording the entire sessions with all video and audio information will enable us having exhaustive analysis. This method presents a major advantage, which is the possibility of reviewing and analysing the gathered data after the observation many times and from different research perspectives. The video recording allows the researchers to easily identify which participant is speaking, to whom and if he involves an intermediary object or not. The video method facilitates also the transcription of verbal interactions. Indeed, we require multiple views of the design activity to be filmed in order to reconstruct later a complete vision of the design session. To this aim, we place four HD video cameras to record different views: Two cameras dedicated to a close view of the participants when they are around the table, to capture who is talking, to whom, in what order. If participants are using a whiteboard or a big TV screen, we also need to have what is written, drawn or projected on it. A last camera hanged overhead view of the table to capture the artefacts, materials and tools produced or used during the session.

Figure 46. Combined view of captured Data

In addition to the four cameras, we placed lapel microphones for each participant. We recorded the audio data through a safe and high-quality equipment. This choice allows having collective audio feedback but also if desired a single audio file for each participant. In order to preserve a smooth running of session, we did not move or reposition any camera. Similarly, the observers were positioned behind the meeting table in order not to disturb the participants nor being intrusive in the design meeting. The figure 46 above shows the final display mixing the four views and audio files in a combined view.

B. Post-processing data

The data obtained from our observations need to be formatted in order to process the analysis. We will present in this section the software we used for exploitation of the data. Later in the next section, we will present and discuss our analysis framework.

1. Coding software: Transana

a. What is TRANSANA?

Transana is a CAQDAS software (Computer Assisted Qualitative Data Analysis Software) developed at Wisconsin Center for Education Research (WCER) by David WOODS. The software is designed for Mac and Windows environments. Transana is based on the grounded theory(Charmaz & Belgrave, 2015), inductive approach and emergence of signifiers from the data. The software is suitable for large multimodal corpus and longitudinal studies (widely used in educational research). The analysis under Transana are based on the transcription of video and audio media.

We can summarise the main functions of Transana in the following three points:

- Organisation of data:

-Transana allows the centralisation, organisation and use of an important corpus composed of heterogeneous data

-The creation of synchronised multiple transcriptions and the alignment with one or more video and audio streams.

- Creation of analytical resources

-Creation of collections of corpuses: coding segments of data

-Categorisation of data using a keyword structure

-Creation of new collections based on the keywords

-Production of reports, diagrams and graphic representations.

- Other functions

- Conversion of multimedia formats

- Data sharing within a group of researchers (Multiple User version)

- Relatively stable and ergonomic software interface.

The following figure 47 presents a screenshot of Transana interface:

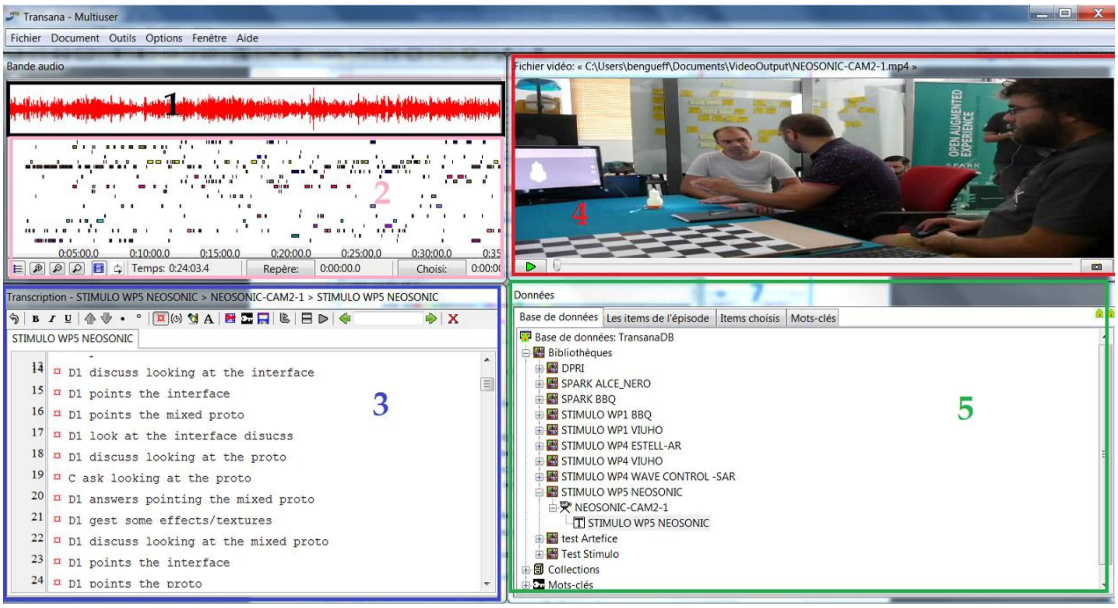


Figure 47. Screenshot of Transana interface

❶The first window presents the audio track.

❷The second window is the repartition of keywords all along the session time

❸The third window is dedicated to transcription

❹ window 4 displays the video data

❺The last section is dedicated to data classification into different collections. Associate to each collection the appropriate video file and transcription file. Later, on the analysis phase, we associate to each interaction a keyword.

b. Transana Selection criteria

Transana facilitates work with the concept of unit of analysis and different time scales including the notion of collection and extract. An elementary unit is the smallest unit of analysis on which the research work is based in order to organize its data (Badreddine & Woods, 2014). The unit of analysis can be at the scale of a word, a gesture, a movement, an elementary action or interaction, etc. or on a wider scale such as a theme, an educational or training phase, an activity, etc. In our case, the choice of this software is directly related to the research objective focusing on the elementary unit of interaction. This choice of research unit is related to the fact that we are interested in studying the evolution of interactions between design participants in different environments.

2. Data processing under Transana

As illustrated in figure 48, we present here a typical example of how we code our corpus under Transana. The steps are the following:

1. Add a video from the Transana database sample to our project, so we are able to analyse it
2. Transcribe the video based on our research aim.
3. Add time codes to allow synchronisation between video and transcription
4. Assign each transcription segment to an interaction
5. Create collections which regroup transcriptions from the same category
6. Create keywords that will be used in a subsequent analysis. The keywords are the elements of our analysis framework (to be presented in the next session)
7. Assign appropriate keyword to each collection
8. Create and customise Transana reports, maps and graphs.

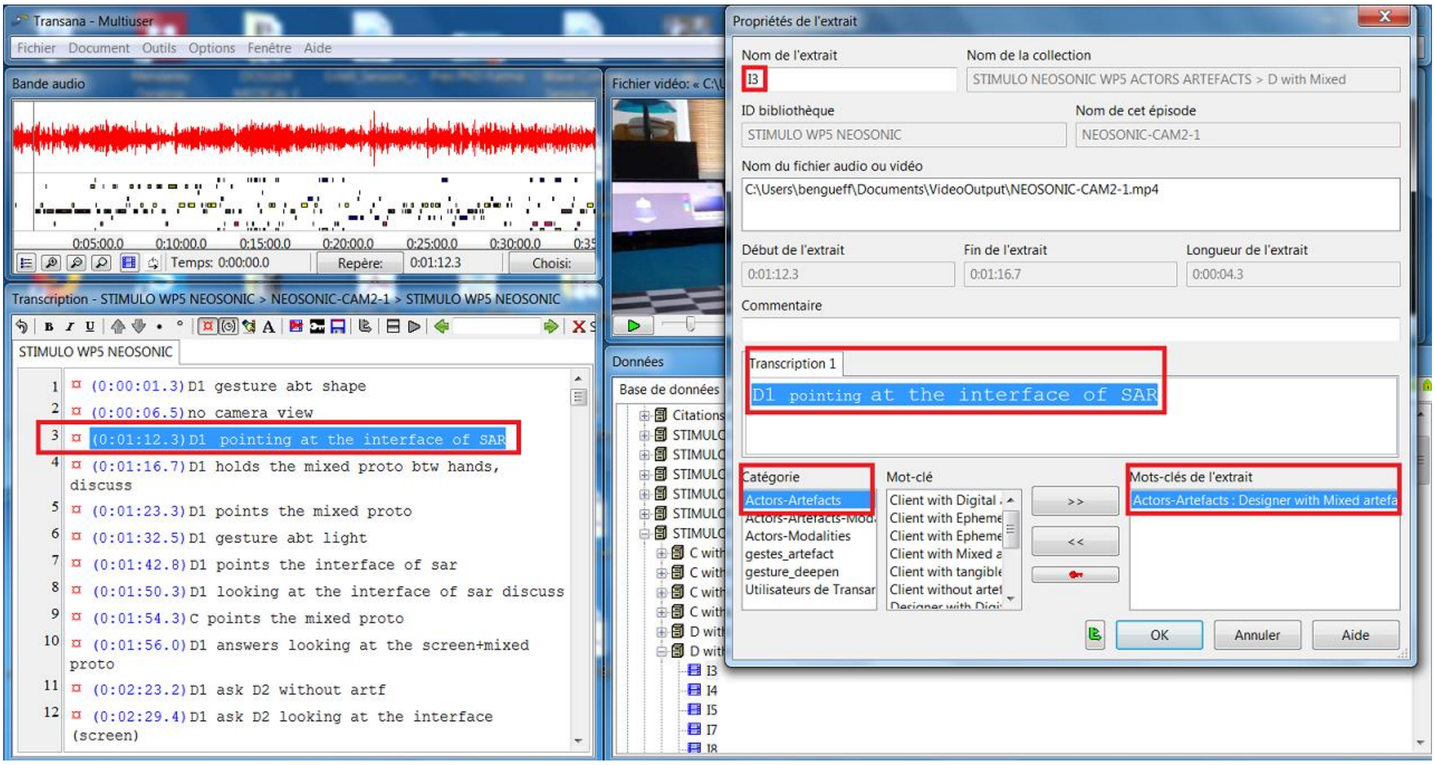


Figure 48. Example of data processing under Transana

When we achieve these steps, the data generate by Transana is analytic data that we will run under Excel (figure 49) to generate our results graphs depending on what we are looking for:

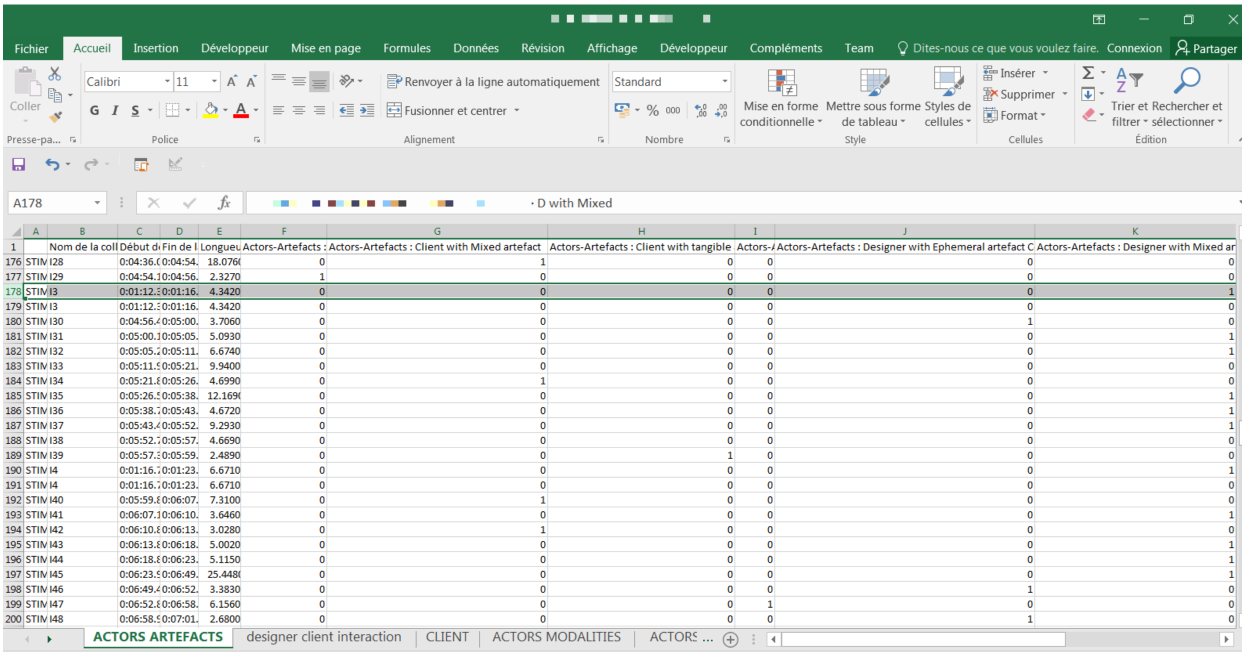


Figure 49. Example of data processing under Excel

The analysis of data under Transana was proceeded following our analysis framework. We present in the following section the method of development of our coding scheme.

3. Analysis framework development procedure

A. Artefact centric interaction analysis

In the previous section I (Chapter1. Section I), we introduced our methodological framework based on design protocol analysis. The aim is to analyse all type of interactions occurring during the design activity. We justified the gestural interaction analysis as an interesting approach to design studies. In line with the literature, we noticed that, while working, design participants involved a great variety of objects. These objects can be physical mock-ups, drawings, printed prototypes, the participants' sketches, etc. Participants interact through these design objects. They talk about it, point or refer to it and sketch on it. These objects were considered by Hutchins(Hutchins, 1995) a mean to express the objective, the function and the constraint. Purcell and Gero (Purcell & Gero, 1998) study the sketching activities and the role sketches play in the design process. Different studies consider the design objects as a communication channel between design actors who have different backgrounds and skills. We can cite Star (Star, 1989) who called them "boundary objects" and Vinck and Jeantet (Vinck & Jeantet, 1995) who coined the concept of "intermediary objects". They state these objects as a mean for analysing and understanding design activity. They consider the intermediary object as mean of representation, facilitating the communication of knowledge and a support for interactions.

After these studies, many researchers continue to use these concepts in their research. If these objects are open to modification and evolution, they are considered by Boujut (J.-F. Boujut & Blanco, 2003) as a mean to foster co-operation.

To conclude, the research method we adapt to study the design activity is the analysis of the design artefacts. We assume that we can reach our research goal by the means of gesture analysis.

B. Definition of our analysis framework

As cited previously in section I (part B), our analysis is based on elementary unit, which is interaction. Our framework entities are inspired from the model of Synchronous collaborative situation model(Prudhomme et al., 2007).

Since the literature studies give a large interest in speech analysis (Austin, 1962) and gesture analysis(Visser & Maher, 2011)(Mcneill, 1994). However, we did not find any reference of analysis to interactions based on artefacts that fits our research requirements. Therefore, we need to build our own taxonomy of gestures associated to artefacts.

We start by defining what exactly an interaction is. We consider that an action accomplished by a participant towards another participant or an object present in the design environment is an interaction(O'Hare et al., 2016). The interaction could be supported or not by means of artefact.

Then, artefacts are the design intermediary objects, which facilitate the interactions, confrontations and interpretations of design activity(Vinck et al., 1996). Vinck and al. confirm that artefacts can help compromises to be achieved between different design actors.

Based on the study of (Tory, Staub-French, Po, & Wu, 2008), we define interaction modalities as cognitive or physical engagement with artefacts; which means the active involvement of design artefacts. It is highlighted in the study of Tang and Leifer (Tang & Leifer, 1988) that design artefacts are important for collaboration but also the mechanics of interaction with these artefacts. Some modalities require physical engagement of the participant such as gesturing, pointing and manipulate different type of artefacts. The last modality, which is viewing, can be defined as a simple gazing of an information displayed on a screen or the artefact in the heart of collaborative interaction. We will discuss this categorisation in detail in the next section.

Therefore, our research aim was to identify:

- Who is initiating the interaction? ➔**Actors category**
- Which type of artefact the interaction involves? ➔**Artefact category**
- Through which modality the actor is interacting with the artefact? ➔**Modality category**

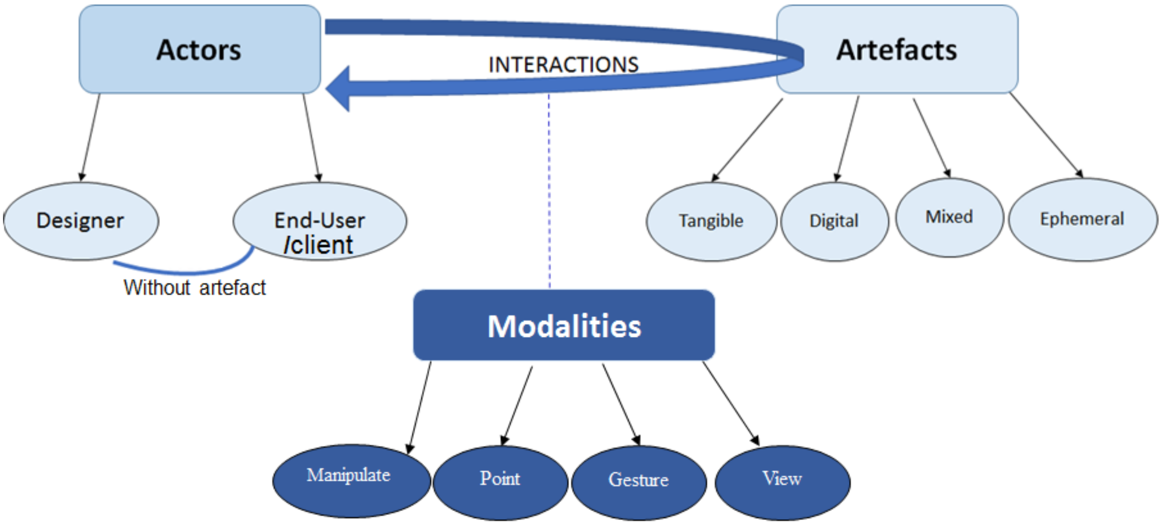


Figure 50. Artefacts-centric Analysis Framework

1. General coding rules

In order to conduct structured analysis on the artefacts presented above, a coding scheme has been created based on the framework presented in the previous section. The creation of the analysis framework is an iterative process. In other words, while coding, we use feedbacks from the coders to improve the initial version of the coding scheme until having a robust version, which fits our requirements, and cover all the coding aspects. It is important also to check the validity of the developed coding scheme using the intercoder reliability method (described in next section). Here are the most important rules we built to correctly analyses our data:

- Our research focuses on artefact-centric interactions as cited above. The content of verbal interactions is not our target; we will only use the speech as indicator of coding in order to identify the actor initiating the collaborative interaction.
- We define an interaction as collaborative (or main interaction) when it occurs at the core of the design activity, which means that it is involved in the product development. We tag a collaborative interaction when a participant initiates an action by speaking or pointing, gesturing in the air or looking at an artefact while talking.
- Then, we identify which actor initiates the interaction. We code an interaction when the action of pointing, gesturing, looking or manipulating is occurring simultaneously with the speech as we are looking at collaborative interactions.
- We define which artefact is at the centre of the collaborative interaction: we qualify that an artefact is at the core of the collaborative interaction when a participant points at a given artefact: this lead to catch the attention of other participants to this artefact. It is also when several persons look at the same artefact or a participant manipulates an artefact and at least one person looks at it.

2. Artefacts typology

Different types of artefact are identified in our design observations. We have four categories: tangible, digital, mixed and ephemeral. They are described in details below.

a. *Tangible artefact*

The tangible artefact category includes all physical design representation present in the meeting room and involved during the discussion. It regroups physical mock-ups, prototypes, drawings, sketches, and printed representations, any notes written on notebook, post-it or paper.

A tangible artefact is involved in a collaborative interaction when the participant (client/end-users or designer) (or more) points at one tangible item. We also code the interaction supported by tangible artefact if the participant talks and holds a tangible artefact in his hands or simply look and talk about it.

b. *Digital artefact*

We regroup under the digital artefact category as any kind of media displayed on any surface such as TV screen, laptop, tablet, smartphone, or any ICT tool. The object can be a presentation including text, pictures or images of the product (mostly), videos.

We consider that a digital artefact is at the core of the collaborative interaction when a participant (client/end-user or designer) (or more) points at a screen, manipulates his phone to search for an information or finally talk and look at information displayed on a screen.

c. *Mixed artefact*

We define the mixed artefact as a physical object (physical mock-up of the main product of session with a predefined shape, built with rapid prototyping facilities) on which we are projecting digital content. These content can be pictures, images, text, textures... We call it mixed artefact because of its nature mixing the physical and the digital in the same representation. This is the kind of artefact which is at the core of the SAR (Spatial Augmented Reality) platform. The part of the SAR system that actors are likely to interact with is the mixed artefact itself and the interface of the software that allows modifications of the digital content. The latter displays (tablet, computer screen…) in real time the textured mock-up of the product under design and, so is possibly a medium for the collaborative interaction. Since we are interested in any interaction with the mixed artefact, we decided to code mixed artefact when the SAR prototype or the tablet is at the core of the collaborative interaction.

A mixed artefact is at the core of the collaborative interaction when a participant (client/end-user or designer) (or more) points at the mixed artefact. In addition, a participant talks and holds the mixed artefact between hands. Mixed artefact is considered as an open intermediary object(Vinck, 2009) since the digital content can be modified, discussed and improved in real time.

d. *Ephemeral artefact*

During the design observation, we identify the cited artefacts' typology, but we also observe interactions without support of digital and tangible objects. Participants were communicating through diverse gesticulations. We include in this category all types of gestures in the air identified during the design observation. The category involves virtual artefacts and communication gestures.

- Communication gestures: correspond to gesturing with hands instead of or while speaking. These hand gestures, beat gesturing (Eris, Martelaro, & Badke-Schaub, 2014)accompany rhythmic pulsations of speech and do not contain task specific content or some symbolic gestures (hello, OK...). This is not a real artefact. This category was added on purpose to facilitate the coding and separate the real gestures involved in the design task and those employed only for communication purpose.
  Communication gestures are basically gesture in the air associated to the speech in order to facilitate information handover. It accompanies the speech with no specific meaning. The actors do not mean any an artefact in particularly.

- Virtual artefact: we define this category to cover the imaginary objects depicted or mimicked by a gesture in the air. The gesturer can depict or mimic an object (shape, volume, surface), a usage (function in a specific context) or a behaviour (deformation of an object, simulate flashing lights). It simulates an action referring to an artefact.
  A virtual artefact is at the core of the collaborative interaction when a participant (client or designer) gestures to simulate a function or an action. In addition, we code virtual artefact, when participant holds an artefact in one hand (tangible, mixed or digital), makes gesture associated to this artefact with the other hand. A participant gestures in front of (or really close to) an artefact (tangible, mixed or digital). A virtual artefact begins at the initiation of a gesture (with the features previously defined) meaning the hands moving from a neutral position. Similarly, the virtual artefact ends when the hands come back to a neutral position(Cash & Maier, 2016). The neutral position does not necessary correspond to a specific position, this is the position of hands just before initiating the gesture (e.g. hands on the table, hands already in the air with elbows on the table…).

e. *Without artefact*

When an actor interacts without referring to an artefact, we code without artefact. Concretely, participants talk and look at each other without any support (no gaze at any artefact, no designation of an artefact and no artefact between hands).

3. Interaction modalities typology

The second level of coding in our analysis framework is to identify which kind of interaction modalities is employed. We need to spot which modality of interaction is more common in design activity. We also want to highlight if there is a preferred interaction modality in both environments. In other words, does design actors have the same privileged interaction modality in standard environment and with a SAR tool?

For this purpose, during our observations, we identify the most common practice of design actors: Manipulation, pointing, gesturing and viewing artefacts.

a. *Interaction modality: Pointing*

We define pointing as the use of a hand, a finger or a pen or any tool to point directly at an artefact or a specific part of a prototype or a content displayed on a screen. Pointing has many meanings in the field of social communication(Tory et al., 2008). However, in environment using ICT tools and GUI interactions, most of the time pointing means the selection of a particular item on a displayed screen(Kendon, 1996).

b. *Interaction modality: Gesturing*

Gestures are defined as interactions involving physical engagement. It implies the use of hands and other parts of the body for communicative purposes. Many studies also define gestures as a complementary means to participants' speech. It aims to express ideas and transmit meaning during collaborative design sessions. McNeill(Mcneill, 1994) affirms that gestures cannot be fully understood without the context of speech. This is why we used transcriptions of the corpus as a complement to our analysis.

Based on our analysis framework, we distinguish between gestures in the air with a purpose of communication and gestures related to the design task. For example, moving hands to indicate an extent of an area, to surround a small area of interest or to use two fingers to indicate space length between are considered gestures in relation with design task accomplishment.(section3.B.1.d)

c. Interaction modality: Viewing

We define the viewing modality as the most obvious interaction. It consists of viewing the information that is currently visible or displayed on a digital monitor to look at the artefact while talking.

d. Interaction modality: Manipulation

The manipulation is an important tool to enhance the interaction process(Pinho, Bowman, & Dal Sasso Freitas, 2008). It includes actions that allow design objects to be touched, lifted, held, carried, dropped, etc. The manipulation category in our taxonomy includes modification of artefacts, annotation and sketch.

- Sketch

We define the sketching interaction as any graphical interaction occurring when a design actor draw on a piece of paper or to make a draft representation. Sketching was a subject of multiple studies. For example(Purcell & Gero, 1998)claim that design typically begins with a series of sketches. (Visser & Maher, 2011) focuses on studying sketches in co-design meetings in the architectural domain. (Goldschmidt, 1991) confirms that sketches allow the externalisation of the design process and enable designers to move from abstract design concepts to concrete form. She even qualifies the sketches as the most important design artefact that permit to structure and organise the group discussion.

- Modification

Modification occurs when a participant interacts with a piece of paper or a computer to make graphical propositions or modifications. When a designer interacts with his laptop to show a power point presentation, we consider the interaction as manipulation.

- Annotation

We consider annotation as a graphical interaction that can be observed on physical artefact. On the paper, the participants made marks on the drawings or annotate some marks on the side of the printed-paper.

Discussion on shared and single interaction modalities

In reference to multiples research studies, we assume that viewing, gesturing and pointing are shared modalities that help design participants to collaborate. We cite Mondada (Mondada, 2007) who confirms that pointing in a co-working setting enhance common focalisation of attention on pointed objects. It involves the attention of all participants and interactions on the pointed object. The work of Pfeuffer et al. (Pfeuffer, Alexander, & Gellersen, 2016) and (Qvarfordt & Zhai, 2005)explore how the users' gaze can support collaborative interaction on digital tools. These cited studies show promising potentials of eye gaze for collaboration. For what concern the gestures, many studies considered as a communication tool(Visser, 2010),(Visser & Maher, 2011)and (Cash & Maier, 2016). Other scientific references such as (Lebaron, 2000) and (Yasui, 2013) examine the role of gesture repetition in joint activity context. They demonstrate that gesture repetition help to build shared knowledge within participants. The studies confirm that gestures play an essential role during collaborative idea construction.

In this thesis, we will consider the gesturing, pointing and viewing modalities as sharing knowledge and communication enhancer. We call them "shared modalities".

Manipulation is the only interaction modality, which present double side: it can be single but also shared interaction. When a participant involves the manipulation modality, he can share his sketch, annotation or modification with others or can keep it for himself. Tory (Tory et al., 2008)affirms that when sketching annotations are shared, they enable the group to mentally visualise the proposed structure.

In the next analysis and results chapter, we will investigate the rate of shared versus single modalities in both design environments with and without SAR tool. We will have then a deeper look on how much SAR tool can boost the involvement of shared modalities in order to enhance collaboration in design task.

C. Validation of analysis framework sustainability: intercoder-reliability

1. Definition

Validity, replicability and reliability were the three criteria mentioned by Bryman(Bryman, 2000) in order to test the validity of social research. The study of Blessing and Chakrabarti(L. A. Blessing & Chakrabarti, 2009), highlights the importance of realising a double coding to ensure the validity of the gathered results. They state, “*Double coding involves coding of at least a part of the data by two different people or by the same person twice but with a time delay in between.*”

We can assume that having a second coder ensure a more objective look at the coding taxonomy and so lead to a more reliable coding process and results. Intercoder reliability is an indicator of measurement consistency. It helps to determine whether two coders are consistent in evaluating a characteristic of a message. Although intercoder reliability does not insure validity, it is a crucial component in content analysis. Without a proper establishment of intercoder reliability, the interpretation cannot be considered as valid and likely to be doubted by reviewers.

2. Method

Two methods were considered to calculate inter-coder reliability between coders:

- Percent agreement: Is limited to nominal coding with only two coders with the same number of coded units. Although it is the easiest way to compute inter-coder reliability, there are some drawbacks, and the use of percentage agreement is not usually recommended(Artstein & Poesio, 2008).

$$intercoder\ reliability = \frac{number\ of\ agreements}{(number\ of\ agreements + number\ of\ disagreements)}$$

Equation 1. Percent agreement index

- Scott's pi (Scott, 1955) and Cohen's kappa(Cohen, 1960) are popular and widely cited method for estimating reliability for nominal data. It is a statistic, which measures inter-rater agreement for qualitative (categorical) items. It is generally thought to be a more robust measure than simple percent agreement calculation. Their advantage compared is that they take into account the agreement due to chance. Cohen's kappa measures the agreement between two raters who each classify N items into C mutually exclusive categories. The equation is:

$$\kappa = \frac{p_o - p_e}{1 - p_e} = 1 - \frac{1 - p_o}{1 - p_e}$$

Equation 2. equation for the calculation for Cohen’s Kappa

Here is the explanation of parameters of equation: p_o is the relative observed agreement among raters, and p_e is the hypothetical probability of chance agreement, using the observed data to calculate the probabilities of each observer randomly saying each category.

The study of Landis and Koch(Landis & Koch, 1977) proposed standards for interpreting κ values (see Table 6). If there is substantial or almost perfect agreement between coders, we can affirm that they are consistent. According to the obtained level of agreement between the coders, then the results of the analysis can be interpreted.

<0	Poor
0 – 0,20	Slight
0,21 – 0,40	Fair
0,41 – 0,60	Moderate
0,61 – 0,80	Substantial
0,81 – 1,00	Almost perfect

Table 6. Standards for interpreting k (Landis and Koch 1977)

3. Calculation

The Cohen's Kappa was calculated to estimate the intercoder reliability regarding our analysis framework.

- First step:

Two different groups of two coders code the same video extract. The following table 7 represents an example-coding sample:

	Coder 1	Coder 2	Agreement / Matching
Occurrence 1	Ephemeral	Ephemeral	1
Occurrence 2	Mixed	Mixed	1
Occurrence 3	Without artefact	Mixed	0
Occurrence 4	Mixed	Mixed	1
Occurrence 5	tangible	Tangible	1
Occurrence 6		Ephemeral	0
Occurrence 7	Ephemeral	Ephemeral	1

Table 7. Sample of coding example

For example, "Ocurence6" was coded "Ephemeral" by coder 2 and not spotted by coder 1. As a result, we find "0" in the last column meaning that there is no agreement between the coders. Similarly, there is no agreement between coders for "Ocurence3" that was coded "without artefact" by coder 1 and “Mixed” by coder 2. For other extracts of this sample, we obtain an agreement between coders (written “1” in the last column), e.g. the occurrence 1 was coded “Ephemeral” by both. At this stage, we are able to calculate the percent agreement.

- Second step:

The data are arranged in a contingency table in order to be able to calculate the Cohen's Kappa.

		Coder					
		Ephemeral	Digital	Mixed	Without artefact	Empty	Sum
Coder	Ephemeral	26				4	30
	Digital		8	1		2	11
	Mixed			21		2	23
	Without artefact				0		0
	Empty	2			6		8
	Sum	28	8	22	6	8	72

Figure 51. Example of Cohen's Kappa calculation

The diagonal in green represents the agreement between coders (i.e. both coded a given event the same way). Others cells represents a disagreement between coders. For instance, in one interaction coder 1 codes a mixed artefact while coder 2 considered as digital interaction.

- Third step:

The two groups of two coders made several iterations in order to obtain an acceptable Cohen's Kappa. The following table 8 presents our results:

	Coder 1 – Coder 2	**Coder 1 – Coder 3**	**Coder 2 – Coder 3**
Video extract 1	0,45 Moderate	0,44 Moderate	0,54 Moderate
Video extract 2	0,64 Substantial	0,67 Substantial	0,72 Substantial

Table 8. Results of our intercoder-reliability

For the two tests groups, our intercoder reliability results are improved in the second video extract. We can consider that our double coding is substantial and validate our taxonomy.

CHAPTER II: Case Studies

Abstract

The second chapter of part II is dedicated to present in details the case studies that form the database of our research work. We first present the design agency, which is our SPARK industrial partner based in Barcelona. Then we present the design agency team members. We focus on their backgrounds, the services they offer to their clients and their methodology of work. We devote a part to the design process the agency follows to realise their projects. A detail description is devoted to different steps of the design process: design approach, design lab, ID definition and the technical approach. The focus on the detailed design process comes from its important role. The choice of design process affects directly the projects involved in our cases studies.

The second part is allocated to the explanation of case studies choice criteria. We note that the selected projects are quite representative of typical project in creative design industries. We also are interested in collaboration design meetings, so we make sure that the clients are available to attend our sessions.

Finally, we present in details the different case studies. We focus on the task realized during the meeting and in which design phase it happens. We are interested in the typology of artefacts involved during these sessions, the profile and backgrounds of actors attending the meetings. Then, we raise the different environments in which the participants are immersed and the tools provided for each case study.

1. Presentation of industrial partner: THE DESIGN AGENCY (TDA company)

1. Presentation of The Design Agency

The design agency is a product design and innovation company. TDA helps companies grow by thinking, creating and developing compelling product experiences. Specifically, the design agency helps clients to identify new business opportunities, create valuable and feasible concepts deliver stimulating products and help the client throughout all the production and implementation processes.

Three partners founded the TDA in 2003. It is based in Barcelona and Guangzhou, China. They have international clients in Turkey, China, Australia, India and Spain. The TDA serves the global market thanks to a good team consisted of eight specialized people with complementary profiles: Designers, innovation planners, engineers and business developers.

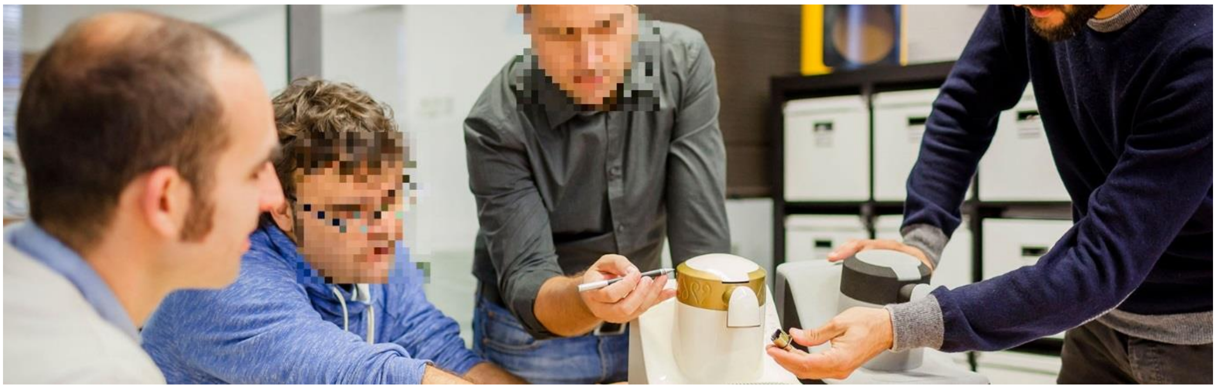


Figure 52. The design agency team in collaborative design session with client(“STIMULO,” n.d.)

2. Background and services of the design agency

The TDA have a strong background on Product Design. In addition, they extent their methodology and problem-solving approach to other disciplines:

- Creating compelling product experiences through innovative Product Design. TDA aims to take their customers from ‘today’ to ‘tomorrow’ products using aesthetics, materials, ergonomics and creativity to increase the value of products.
- Technical challenges faced by mechanical engineering, electronics, materials, components, tooling, lab tests… are some of the tools used to deliver working prototypes, pass regulations, and smoothly move into mass production.
- Service Design Providing compelling experiences: Service design favours the implication of users in the design process. The users are at the core of the design task conducting investigations with them, co-creating with the clients, prototyping ideas and testing them. Using these methodologies to finally deliver meaningful experiences for customers.
- Engaging digital experiences through Interaction Design. Providing meaningful communication in between the audience and customer’s products and services, transforming user’s needs into positive interaction touchpoints.

3. The 4D Methodology of TDA design agency

The design company (TDA) methodology is composed of a 4-step itinerary that guide the project from detecting business opportunities to production. The methodology chosen is the 4D: Define, Design, Develop and Deploy. This methodology is agile, centred on the user, oriented to the market need. The design company is based on engineering and design creativity to ensure the delivery of products.

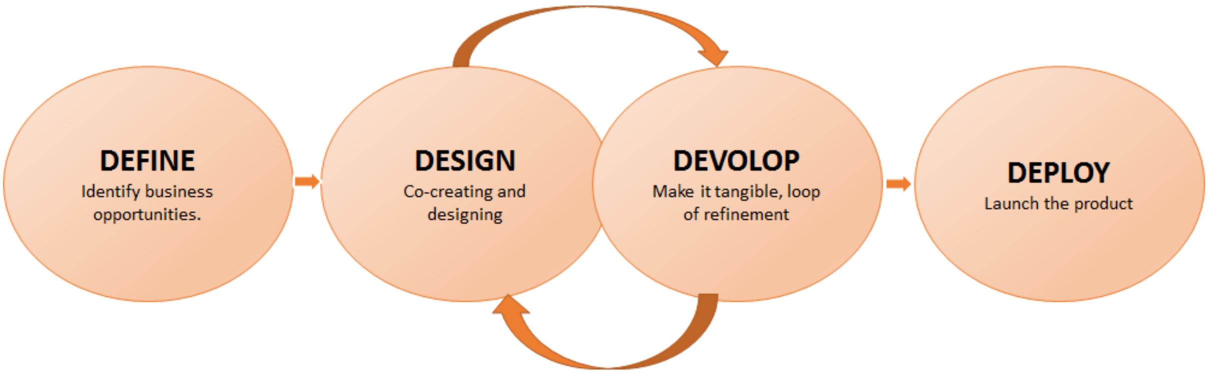


Figure 53. Methodology of the design agency

This 4D methodology is applied to diverse areas of activities:

- Consumer Projects target the individual. Involving sectors like appliances, sports, consumer electronics, homeware and outdoor leisure.
- Equipment Projects for B2B companies targeting professional workers or institutions. Includes street furniture, service equipment, safety devices and installations.
- Healthcare Products and services made up for medical-related clients. Healthcare equipment, devices and improved patient experiences.

4. Description of design process at the design agency

The ultimate goal of the design agency is to create more competitive and innovative products for their customers. In order to achieve their aim, they define their own design process presented on the following illustration:

Figure 54. Description of the Design process

- **Design approach**

In this step, the design team gathers and analyse relevant information to discover insights and opportunities that will inspire the designers from a strategic point of view, taking into account three principal dimensions: the target users and their demand, the appropriate technology to be involved and the business constraints.

This stage includes target audience analysis, uses analysis, key purchasing criteria, product background and competitors benchmark. Once the team gather all these information from the design debrief, they start working on strategy which ensures that the new design will be aligned with the client's business plan.

- **Design lab**

Design lab is a powerful creative tool to generate exciting design proposals, where insights will be translated into meaningful products experiences. Design directions : using lateral thinking technics and own developed creative sessions, we strive to generate new ideas aligned with the briefing. Each direction will include functional improvement and a specific aesthetic style, using hand sketching and draft 3D files to present the directions. Their core service is around exploring ideas, visualise them, and select the best option.

Design proposals: once the direction is clear, the design proposals stage will focus on deciding about the design language, by presenting different aesthetic solutions and chose the one that fits better with the brand, and generates the best emotional links with their customers. 3D surfacing software are used in this stage in order to make sure that the results are correct in terms of dimensions and proportions. Fast mockups will be delivered to check the shape and proportions. Using rapid prototyping or hand modeling at a basic resolution.

- **ID Definition**

This stage takes the selected design proposal and transforms it into a refined design. Its main purpose is to mature, polish and do final touches while making sure that production requirements and costs stated in customers' design brief are kept.

It starts with a Design refinement: During id refinement stage, designers can focus in the details, exploring different solutions to each part of the product. The final design must be aligned with the brand expectations and generate a positive impact to users, so they make sure the product creates emotional link with the customers. This stage includes building 3D solid files that can be used for prototyping purposes but are not suitable for production.

Then a second step is taking care about CMF: colours, materials and finishes. The interactions of colour experts are essential in order to remain the customers' business identity. The TDA constant research efforts allows them to provide their clients with the latest CMF proposals. CMF can actually make the difference in between a great or a substandard product.

- **Technical approach**

Having an outstanding design is great but ensuring its technical feasibility is necessary if we want that the product hit the market. Even though the product design service is not meant to go deep into engineering and manufacturing, engineers will deliver to their client a technical report to make sure the product is feasible and workable. The technical approach includes many outputs such as general dimensions, assembly and parts, internal components, materials and processes and technical challenges to be solved during the engineering stage. In addition, it gives a first cost estimation.

2. Case study selection criteria:

The aim of this task is to choose the most relevant case studies from a range of projects proposed by our industrial partner. The chosen case studies should have relevant characteristics to let us study and analyse the dynamics of collaborative design interactions.

In the following section, we describe the main criteria used to identify suitable case studies:

1. Cases studies representative of typical project in creative design industries:

We aim to study projects, which are potentially enabled the use of ICT tool supported by new technology such as the spatial augmented reality. We choose cases studies that can be conducted by both standard and innovative technologies. Considering that the creative industries include heterogeneous products, it is also necessary to have case studies that reflect the variety of projects completed by design agencies in this sector. The selected case studies from our partner should be representative not only of the design activities running in this company, but also of a wide range of tasks typical of collaborative design industries.

Finally, we select ongoing projects to ensure actual engagement of the design team.

We consider criteria also for the product choice. Since we will be working on diverse projects, the chosen products should be consistent in term of level of complexity, the design working phase and the duration of sessions.

For what concern the team criteria, we chose that one design team carry out all the sessions

2. Availability of client and stage of project

Our observations target was to work with industrial ongoing projects involving real clients therefore we can compare the design interactions to later observations sessions in lab run with recruited end-users.

It was therefore necessary to select case studies that would fit with the phase of the project that can involve clients. In addition, suitable representatives from the client companies had to be available to participate in the meetings.

3. Presentation of case studies products: artefacts, tasks, actors, environment observation process

We consider in this part, a detailed presentation of the use cases selected to be recorded and analysed in our research work.

Two sessions took place in the design company premises in usual settings of designers' daily work. These meetings involved TDA clients'.

A usual working session starts with a presentation of designers' work and proposals to their clients, then the designers collect the client's feedback and, finally, there is a joint discussion on the evolutions, possible improvements of the ongoing proposal. We set our cameras and microphones in the meeting room in order to record the flow of the discussions.

In addition, three other sessions took place at G-SCOP lab were we reproduced the design company's environment as much as possible. In order to achieve our goal, we selected active projects consistent in terms of task, actors and duration, in order to minimise as much as possible the differences with the other case studies. In addition, we ensured that same design tools were provided to the participants.

A. Case Study A at TDA

1. Presentation of the client's company

The design agency client is an Australian company producing barbecues for more than 30 years, mainly as an OEM business. In 2016, the design company started to work on the new client brand; define a range of gas barbecue and accessories. TDA team are currently working with the client to define the 'Product DNA' to apply to the new items. The project is being conducted with the client European office in Holland.

Figure 55. Design team working with Client A

2. Object

The principal object of the session is a selection of barbeques. The team work to achieve a final BBQ that has a good balance of robustness and elegance. They want an eye-catching final product, powerful and close to what buyers would like to set in their houses. In addition, the team want to join other convenient features such as an enlarged countertop workspace, an accessory convenience drawer, a complete accessories system to be attached in the perforated sides of the BBQ, a fat-free Grill smart cooking system, and a see-through roasting hood, among others things to made this product more attractive to buyers.

Figure 56. Product of Case study A

3. Task

In order to seduce international buyers, the design agency and the BBQ Company collaborated to develop a new range of barbeques specifically designed for DIY stores. The observed session is in the ID Definition phase of design. The task of the session is to discuss each part of the BBQ in order to fit the global new company values and design language. The discussion is based on previous meetings of Design Lab where they already define together the design direction according to brand and product specifications.

4. Actors

The actors attending the meeting from the design agency were the creative director and the chief engineer. Both of them are designers. They involve with them the CEO Europe of the barbeques brand who is a sales expert.

5. Environment and artefacts involved

The session run in the showroom of the design company premises. The design team provide nine real barbecues (BBQ) in the room. To support their discussion, the designers supply printed concepts and BBQ parts on paper, some BBQ knobs to be tested. They also put some coloured post-it, papers and pencils for taking notes. We notice that no digital tool was provided for this meeting, but during the discussion the actors feel the need to visualize videos therefore the client bring his laptop in center of discussion table.

Figure 57. Different artefacts involved in case study A

B. Case Study B at TDA

1. Presentation of the client company

The client of this case study B is a Catalan start-up company founded in 2015. They collaborate with the design agency to set a satellite-tracking device. Their first collaboration was about defining a design to launch a crowdfunding campaign. In 2016, the functions and internal components are fixed and the design agency is now ready to work on the 'ID definition', user interface and user interaction design as well as technical design.

2. Object

The product is a communication device and emergency beacon for use in remote locations as presented in Figure 58.

Figure 58. Product of Case study B

The product is able to send and receive messages even when mobile coverage is not available, via satellite, and allows the user to activate SOS alerts and send and receive messages wherever his location is. The product is a satellite connection device that enables the user to be always connected, in touch, and safe. The design agency is integrating this service into compact, robust and attractive device following design DNA of its client.

3. Task

The client ask the design agency to define a Design to last for their satellite connection device. Therefore, the design company is considered as a long-term partner who takes care of the product design: the potential solution need to have a beautiful look and to be durable and robust.

The design agency discuss with the client the choice of a double injected plastic base made out of a combination of an abs plastic and thermoplastic rubber to reach for an IP67 watertight case which can endure the toughest situations. Special attention will be given to the texture of the rear rubber case, which has been inspired on the contour lines you can find on a topographical map which indicate slopes and gives an extra visual and tactile aspect.

4. Actors

The actors attending the meeting from the design agency were the creative director, the business developer and the chief engineer. Three of them have strong background on design. They involve with them the CEO of the satellite-tracking device brand who is marketing expert.

5. Environment and artefacts involved

The session run in the meeting room of the design company premises. The design team provide multiple satellite tracking devices, an electronic device plugged to a laptop to test the signal operation. A PowerPoint presentation was displayed on a big TV screen in the meeting room. The presentation resumes the important points to be discussed during the meeting. To support their exchange, the designers supply printed different parts of the device. They also put some coloured post-it, papers and pencils for taking notes.

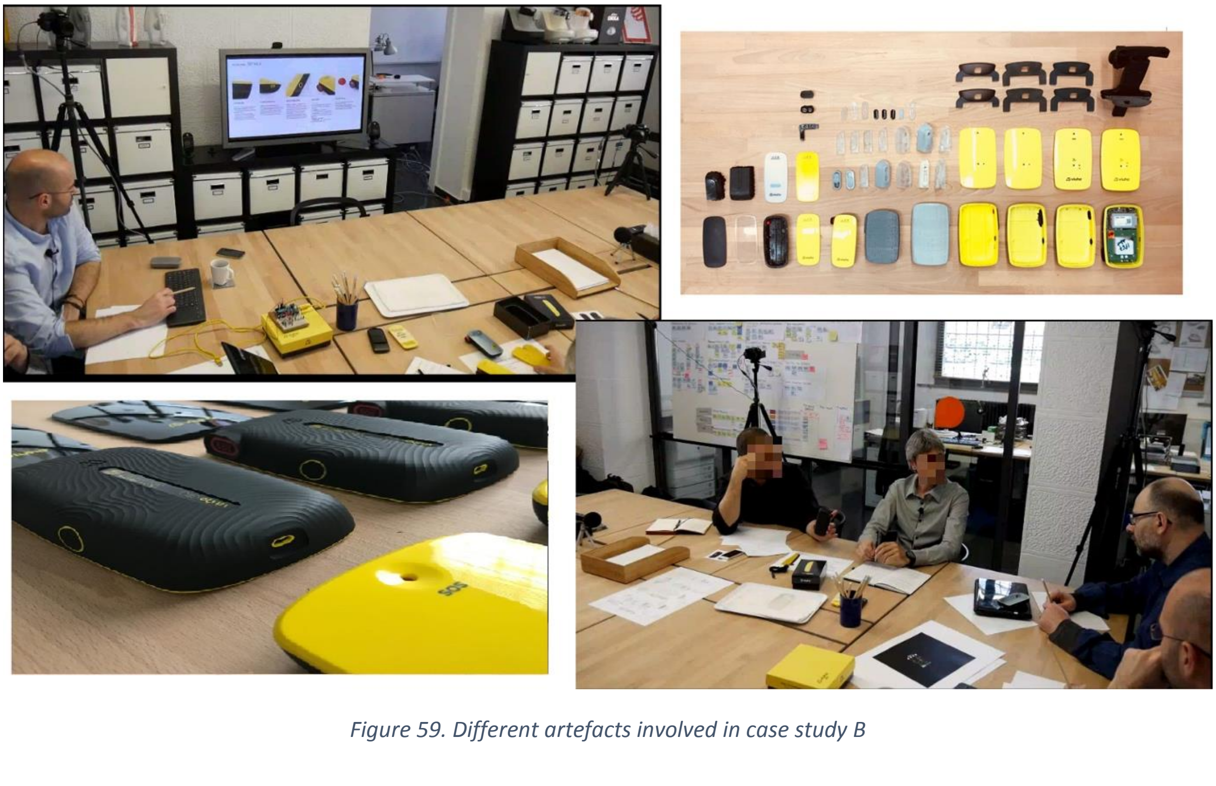


Figure 59. Different artefacts involved in case study B

C. Case Study C at G-SCOP

1. Presentation of the client company

The client of the case study C is the same company as case study B. it is a Catalan start-up company founded in 2015. They collaborate with the design agency to design a satellite-tracking device

2. Object

The object of the session is a satellite-tracking device that aims to guarantee safety for users, peace of mind for those who love adventures. The satellite communication device is an emergency help button for everyone with an exploring and adventurous mind-set. Especially designed for situations where there is no mobile coverage, in extreme outdoor situations.

Figure 60. Product of case study C

3. Task

The overall aim of the meeting run in our GINP lab was that designers define together with end-users the colours, materials and finish of the main packaging for specific environments like the mountains. They also plan to define the final location and pattern of LED status lights. The designers set the meeting armed with diverse suggestions of colours, materials, logo and led location on the device. They want to ask the potential end-users about their opinions on the satellite-tracking device look: colours, textures and materials used.

4. Actors

The meeting involves one designer from Design Company and three end-users. Two end-users are engineering design students and the last one is an administrative staff. The three participants have strong interest on outdoor activities. They already practice hiking and sailing. These profiles are potential users for equipment like the satellite-tracking device.

5. Environment and artefacts involved

The case study C is a close reproduction of the case study B. For this case study, we will be reproducing faithfully the usual running of collaborative design sessions that were captured in the partner premises. The aim of this reproduction is to evaluate the rate of change when we move designers from their standard place of work and change their design partner from real clients to end-users. For this observation section, we present the reproduction of case study C session in our Grenoble INP lab. Supported by our industrial partner, we provide multiple satellite tracking devices with different colours. A power point presentation was prepared by the designer and displayed on a big TV screen in the meeting room. We also print the slides of the presentation to facilitate to end-users following the running of session. The presentation resumes the important points to be discussed during the meeting. To support the colour discussion, the designer brings a colour pallet. We also put some coloured post-it, papers and pencils for taking notes.

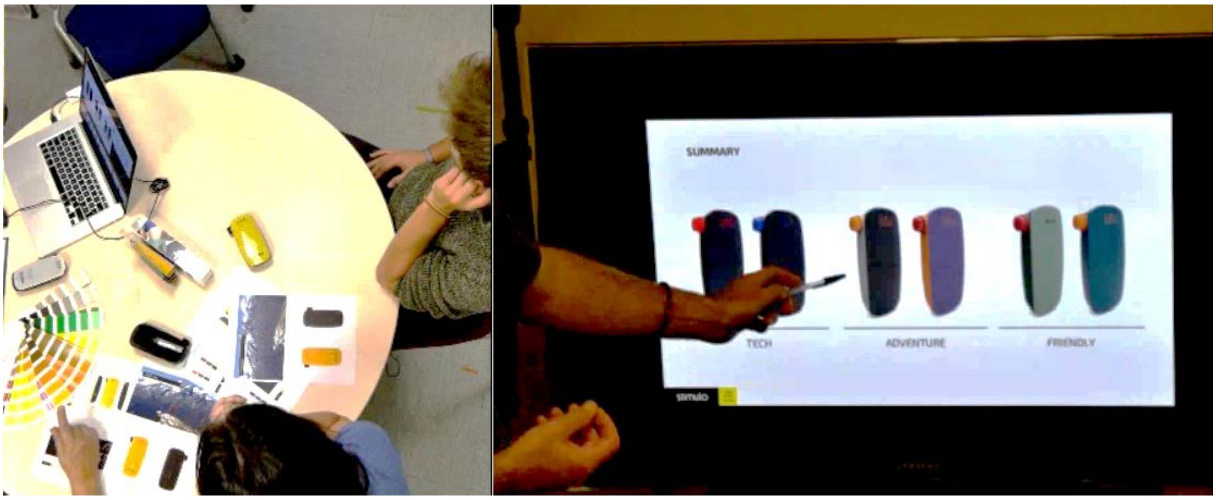


Figure 61. Different artefacts involved in case study C

D. Case Study D at G-SCOP

1. Presentation of the client company

The client of case study D is a leader group who has been innovative in the field of metallurgy for more than 40 years. The services of this company are all related to stamping and machining of non-ferrous metals and steel. The knowledge and experiences acquired after having projects in a wide variety of sectors led to a collaboration with two main universities of Spain and resulted into the development of a strength measurement sensor for fitness purposes.

2. Object

The collaboration of the design agency and this Group provide a strength sensor and accessories to fitness lovers.

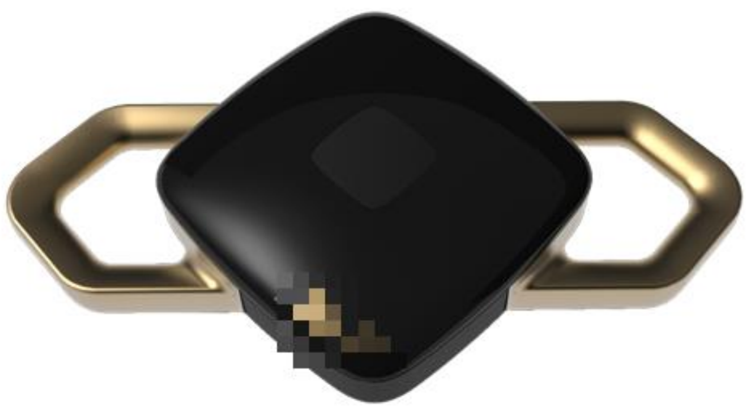


Figure 62. Product of case study D

This sensor developed is able to process the dynamic and isometric strength, which allows the athlete to exercise safely, improve his performance level and physical condition.

A simple electronic tool dedicated to influence the user training routine. The use consist on three elements: an app, a sensor and a training set. To achieve their goals, athletes have to personalise the setup through the app. Secondly, synchronise the bands sensor to the app and finally start their training session anywhere. The results of their efforts applied on the sensor will be displayed on the app at the end of their training session.

3. task

After the integration of electronics, hardware and software the sensor is working. Now the problematic is how to make this sensor a marketable product. The design company task is how to switch from technological concept to an attractive product.

Figure 63. Product of Case study D

The task in this meeting is exchange with potential end-users about the look of the sensor. They need opinions about their proposals in order to get an energetic look for the product. Discussion will be around the colours, materials to be used and textures for a sporty, strong and high-tech design element look.

4. Actors

The actors attending the meeting from the design agency were the business developer and the creative director. Both of them are designers. They involve with them three end-users; two engineering design students and a professional photographer. The recruited end-users have strong interest on workout activities.

5. Environment and artefacts involved

For this case study D, we set a collaborative design session within the integration of an existing ICT tool provided by our partner in Politecnico di Milano. In this condition, we run the meeting in our lab. We provide participants with an augmented Reality version of SPARK platform. The tool is composed by two tablets and an augmented reality marker.

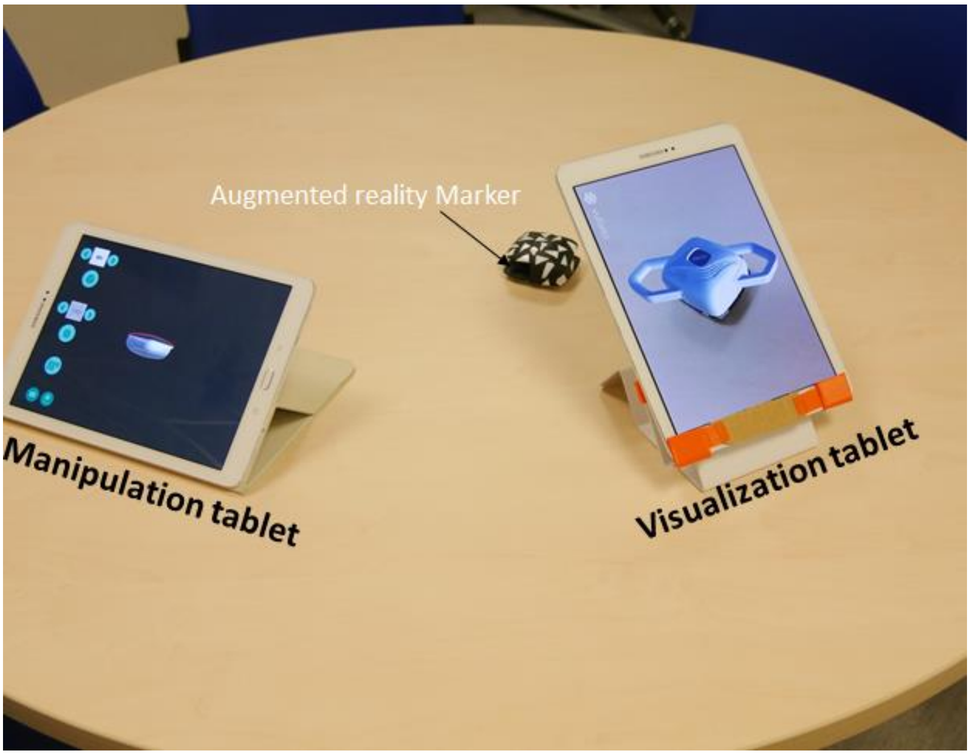


Figure 64. Augmented reality tool for case study D

The creative director of the design agency manipulates the first tablet. Based on participants' suggestions, he is modifying in real time the look of the equipment 3D model. The second tablet is hold by the end-users in front of the marker, so they can visualize the modifications.

For what concern the artefacts used during this meeting, we provide participants with a tangible mock-up of the sensor and a notebook for the business developer to takes notes on the end-users requirements and/or recommendations.

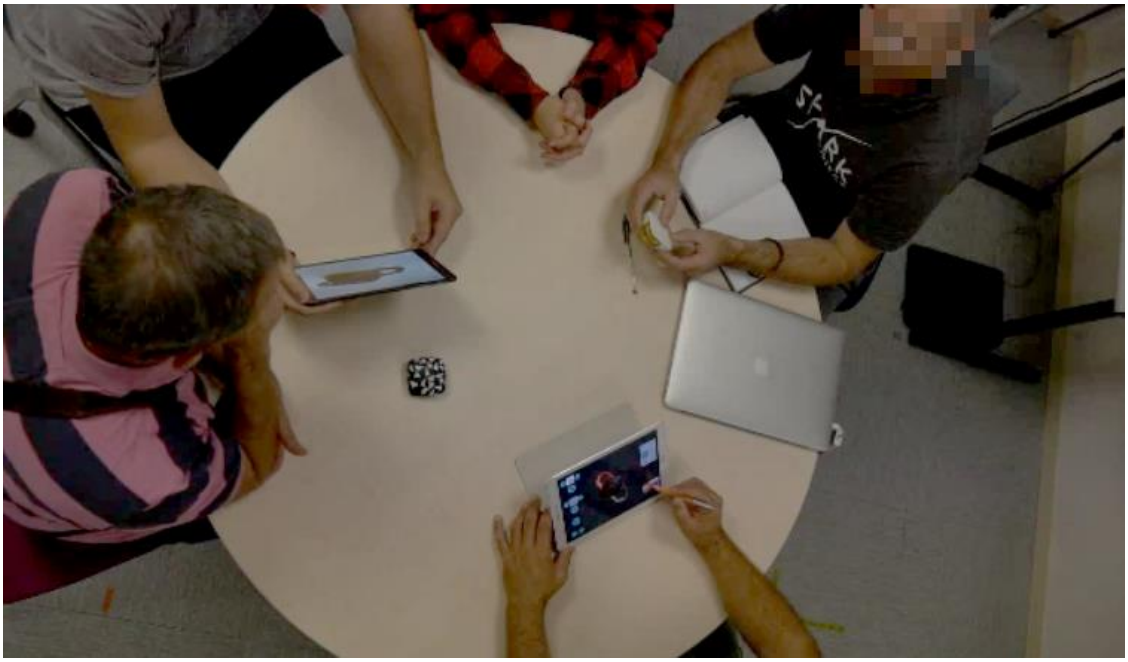


Figure 65. Different artefacts involved in case study D

E. Case Study E at G-SCOP

1. Presentation of the client company

Client Company for case study E is an international engineering company, founded in 1997 and specializing in the measurement of electromagnetic fields. It has headquarters in Europe and United States with a large network of distributors in more than 50 countries. Their laboratory is certified ISO 9001 and ISO 17025 in quality control systems. The principal field of work is designing and developing tools for measurement, monitoring and evaluation of human exposure to electromagnetic fields (EMF). They collaborate with the design agency on their newest innovation project looking for a solid partnership for a full package product development.

2. Object of the session

The main object of session is a personal monitor, which gather all necessary functionalities for a correct and effective oversight of electromagnetic fields exposure. It can detect and alarm the user if he is in a dangerous level of radiation. It has multiple sensory feedback system with a definable trigger threshold that covers audible, visible and vibratory alarms for maximum security.

Figure 66. Product of case study E

This equipment is dedicated to professional users working in harsh, high-altitude and risky environments. In these cases, if we detect electric and magnetic field correctly, we can save people's lives.

3. Task of the session

The design company was responsible for EMF Monitor since early stage of design process. From idea generation phase, early concept sketches, to Design iterations and 3D CAD modelling. The meeting run around the personal EMF Monitor comes after multiple iterations, once the design is reached, and a strong verification of final design through several prototypes is done.

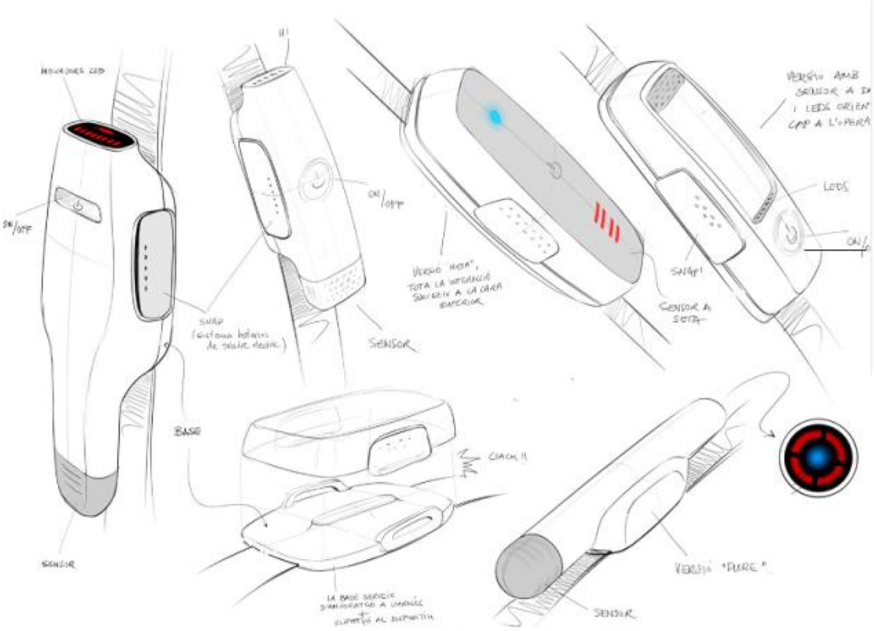


Figure 67. Product of case study E

The designers before meeting their client, they prefer to test the effect of different colors on the product and gather feedbacks from end-users about interactions with different parts of the EMF monitor

4. Actors involved

The meeting involves the business developer and the creative director from Design Company and three end-users. An engineering design student, a PhD student and an administrative staff.

5. Environment and artefacts involved

The case study E is a close reproduction of the usual running of collaborative design sessions that were captured in our partner premises. This case study is a collaborative design session using Spatial Augmented Reality technology. During this meeting, participants will test the SPARK platform in a controlled environment provided by GINP lab. The platform set for this observation is the official 'release 1' of the SPARK platform. We provide a manipulation tablet as interface of SPARK platform and mixed prototype in which we visualize 3D projection of EMF Monitor. A power point presentation was prepared by the designer on his laptop and displayed on a big TV screen in the meeting room. The presentation resumes the important points to be discussed during the meeting.

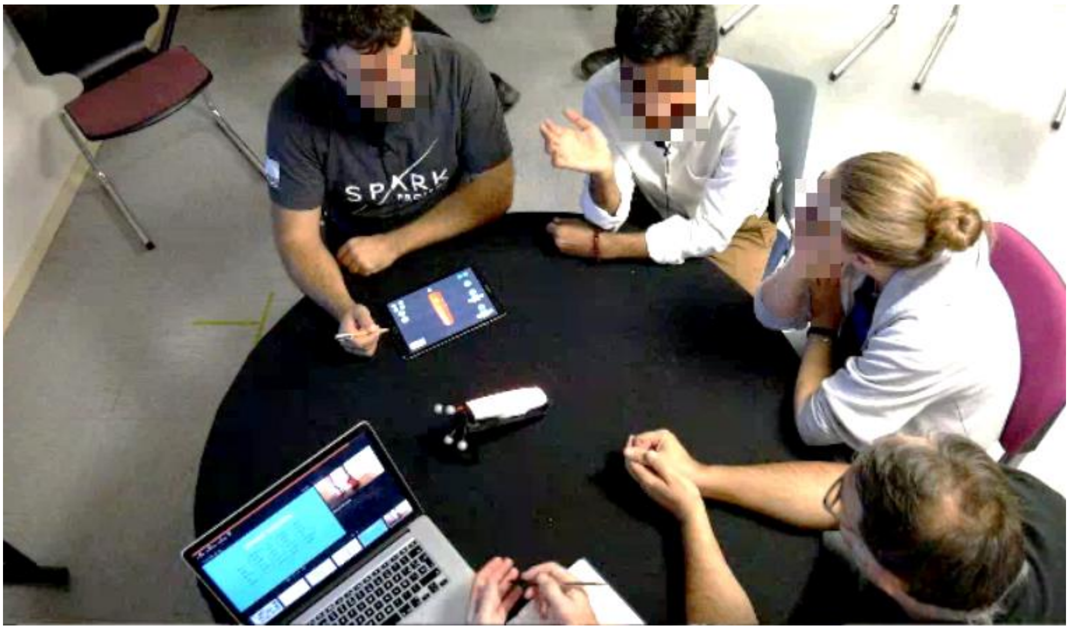


Figure 68. Different artefacts involved in case study E

F. Case Study F at TDA

1. Presentation of the client company

The client of case study F is a Spanish company set up in 2015 by a young PhD innovator. They collaborate with TDA to design a medical device. Their mission is to develop a non-invasive technology for screening and monitoring infections of new-born babies. The collaboration with the design agency target quick, easy and cost-effective solutions.

2. Object of the session

The principal object of the session is a non-invasive device for the detection and prevention of meningitis for newborns. The meningitis illness is hard and confusing to be detected. The main symptoms is fever, which can be caused by any other infection.

Figure 69. Product of case study F

The medical device proposed can detect the disease quickly in order to speed up the process of hospitalisation. The detection happens through a quick unmasking of body fluid infections.

3. Task of the session

For this case study, which is the most recent one, the design agency start a new form of design process. They decide to skip the traditional way of design process and become more agile in their methodology. Therefore, the session was bout checking the minimum viable product using basic prototype.

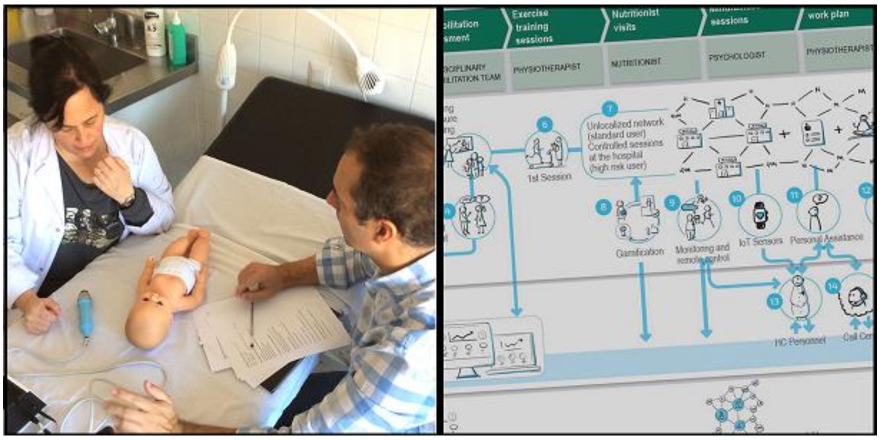


Figure 70. Design team discuss with Client Case study F

They organise the session in different steps: first, they will gather feedbacks from their client about a range of assets. Then, together with the client, they will define the best prototype to be developed. Finally, they will choose the totality of graphic elements for the selected proposal in order to shorten the number of iterations.

4. Actors involved

The participants attending the meeting from the design agency were the creative director and the design engineer. They involve with them the founder CEO of the medical device brand who holds a PhD in Biomedical Engineering has expertise in Medical Imaging and holds a master's in Business Administration.

5. Environment and artefacts involved

The case study F run in the SPARK meeting room of the design company premises. This room is equipped by the necessary tools to run a spatial augmented reality platform: two video projectors, Infrared cameras to track the mixed prototype, a 3d prototype equipped by markers.

Figure 71. Different artefacts involved in case study F

The design team provide a doll playing the role of a newborn so they can test the 3D prototype on top of it. The interface of SPARK platform is displayed on a laptop screen in order to share with the client the steps of graphic elements choice. They also bring their notebooks to take some notes during the discussion.

CONCLUSION OF PART II

Part II covers two main chapters. In the first one, we present in detail the methodological framework and related tools adapted to our research context.

The methodological framework is based on protocol analysis method. Based on the definition of protocol analysis, being the capture of multimodal data recorded from human activity, we select it as the adequate method for our research goal. The design protocol analysis allow us to gather exhaustive data during collaborative design observations. Later, we focus our research from gestures analysis and artefact centric interactions point of view. This analysis framework fits our research aim to study the typology of artefacts involved by the mean of gestures. We dedicate a section to the observation protocol, so we can explain the steps of how we set up our observations in different environments trying to fix up all the variables.

The data management section is covering all aspects related to data capture and its materials. Then the data analysis process under the methodological tool Transana. These analyses were performed using an analysis framework that we develop to correctly achieve our research goal. Our taxonomy answers questions related to:

- profile of actors initiating the design interactions,
- typology of artefacts involved in design interactions,
- Nature of interaction modalities engaged by design actors.

The second part presents our industrial partner, the design agency. We detail their background, type of design services they offer to clients, and we describe their design process.

Finally, we present cases studies A, B, C, D, E & F. We start citing the selection criteria of these specific cases studies, and then we detail for each one its own settings, environment variables products, and especially the nature of design task to be conducted in collaboration with external stakeholders.

PART III: RESULTS AND ANALYSIS: IMPACT OF SPATIAL AUGMENTED REALITY ON COLLABORATIVE DESIGN PROCESS AND STAKEHOLDERS' IMPLICATION

Abstract

Part III presents the observations of collaborative design meetings in different environments as introduced in Part II.chapter II. It aims to answer our research questions about the influence of integration a Spatial Augmented reality platform in collaborative design interactions. This research work was carried out in industrial environment and at Grenoble INP lab. Our proposed analysis framework is centred on interactions based on artefacts. Here, we will present the analysis of our observations under this framework.

The observation has been conducted six times in three different conditions with the same protocol. As a result, six collaborative design sessions have been captured. In Chapter 1 and 2, we discuss our hypothesis based on the analysis of the role of artefacts, their typologies and the nature of interactions modalities occurring during collaborative design sessions. The findings are presented and interpreted in order to answer the research questions (Chapter 3) associated to the role of client and the impact of the augmented reality artefact in the collaborative design task.

We spot that the integration of spatial augmented reality technology in design meetings changes the sessions' profiles regarding the use of artefacts. It enhances the collaboration around the technological tool and limits the use of traditional design representations. Through the results, we also demonstrate how SAR prototype improves the ephemeral artefacts within collaborative design meetings. This indicates an improvement of communication between design stakeholders. To summarise, Part-3 presents the way that the gathered data is analysed, and discusses the findings related to our research questions.

CHAPTER I: Standard situation: collaborative design sessions with standard ICT tool

Abstract

This chapter is dedicated to the first set of observations. These sessions were run with tangible and digital standard design representations. We did not integrate any innovative technology, trying to copy as much as possible the traditional working environment. This is why we call these sessions "standard sessions". Three collaborative design meetings were captured: two sessions were set at the partner's premises with their clients and the third one was conducted at G-SCOP lab with end-users. For the last session, we reproduced very closely the same working environment than the one of the Design Company. We invited designers to our lab with recruited end-users.

This chapter describes the sessions in terms of interactions based on different artefacts, the interaction modalities used, and we draw the participation's profile for each participant. Finally, we discuss the hypothesis based on the design session profile. The results show that case study A and B run in the design company premises are very close in term of artefacts used and interactions modalities involved. Their clients present an interesting participation profile. However, case study C presents a different profile in term of most involved artefact, in the most used modality but especially in term of end-users' participation in the design task which is very limited. This suggests that profile of external participants (or non-designers) is important as they behave differently.

1. Collaborative design in standard situation

In collaborative design sessions, participants use and produce diverse design representations. These design artefacts can vary in representation, modality and range from paper sketches, drawings, storyboards, foam and cardboard models and so on (Vyas, 2013). An analysis of design artefacts produced during a collaborative product design project can lead to useful information for understanding the practices of designers.

In this section, we observe in standard condition how designer practitioners collaborate and through which means. In particular, we aim to identify the rate of physical and digital tools used in their everyday work. We need to draw the profile of each participant in order to analyse later the effect of technology integration in collaborative design session.

2. Observations:

The first set of observations involved tangible design representations and standard ICT tools. The sessions A & B were run in the design company premises with usual settings of designers' daily work. The only different point from a usual session is that our cameras and microphones were placed in the room recording the flow of their discussion. Session C was a reproduction of the design environment in our lab. The same design tools were provided, and we involve end-users instead of clients.

The analysis of this set of observations spots the interactions occurring between the participants, the nature of artefacts involved and the type of interactions modalities used. As detailed in the previous Part II. chapterI, we analyse the recording of the standard meetings with dedicated software Transana that allows a multimedia qualitative analysis mixing verbal and visual data.

- **Discussion on normalised data applied for the whole set of data (the 6 gathered sessions)**

As cited before, our choice was to proceed under Transana the gathered data from observations. We select the tool that allows us to analyse the corpus based on elementary unity, which is interaction.

Our expectation is to evaluate the potential impact of Spatial Augmented Reality technology on interactions between participants in collaborative design meetings. The data as generated from Transana after the post-processing phase present a critical confusion. Following our analysis framework, we assign each interaction to each actor category: the actor initiating an interaction is coded.

Example: if the designer initiates an interaction with a physical mock-up, we code it: Interaction of designer with a Tangible artefact. However, the sessions may present different number of designers and clients or end-users. Following our coding logic, we will not have a proportional interaction rate for each design actor. However, we will get interaction rate for each actor category. In our case, the purpose of normalising data is to achieve comparable results issued from various sessions with different technological conditions. In order to avoid confusing analysis results, we go through the normalisation of each interaction category: in other words, the total number of interactions for each category is divided by the total number of actors (from same category). Example: if the session involves two designers and three end-users, interactions coded initiated by designers will be divided by two. The interactions coded initiated by end-users will be divided by three. In order to set properly the normalisation of data, we calculate an average of interactions assigned to each design participant. Then, once we have a proportion assigned to each participant category (client or Designers) we can later evaluate if the SAR technology does enhance more his participation or not.

A. Case study A

As presented in the second chapter of Part II, the case study A was about discussion on the client's strategy for his new line of products and its implementation in the design of different parts and elements of the barbecues. During this session, the design agency team received the sales manager of the barbeque brand in their premises.

The plan was reviewing general ideas generated during previous meetings such as matching target users, cost and assembly time, etc. Then they focused the discussion on specific parts of the barbecue: hood, grills, fascia, and placement of the logo on knobs and the potential integration of a digital interface on the barbeque. The meeting room was equipped with a set of 9 barbeques, so the client could compare the propositions, manipulate and test them. As a last point, designers and their customer tried to define future work and plan future-meeting dates.

Figure 72. Illustration of Case Study A

This meeting occurred in a relatively late stage of the design process. The discussion was on details of the design and the major decisions on technology and product's architecture has been made before. In this session, discussion was manly on some details of the look and ergonomic aspect of the product. Mainly referring to user experience.

1. Profile of artefacts:

a. Role of artefacts in the session

Using our analysis framework, we aim to analyse and identify the place and importance of artefacts in co-design session.

Our analysis demonstrate that various types of artefacts supported 89% of the total session's interactions. This finding confirms that the artefacts play a key role in the co-creation design session. The figure 73 below clearly illustrates this fact:

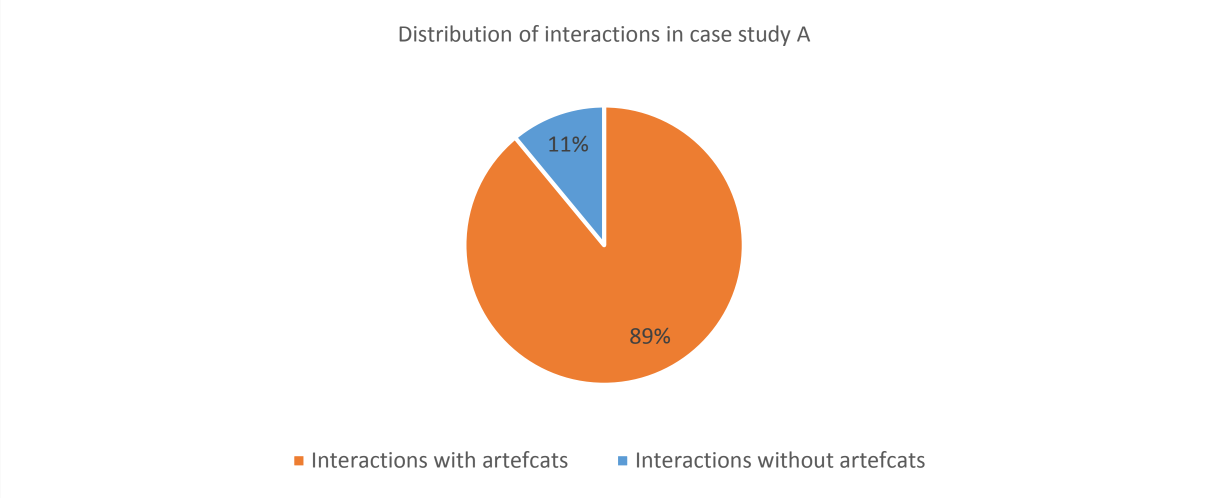


Figure 73. Total number of interactions Case Study A

Only 11% of session total time were not supported by artefacts, which is equivalent to 10 minutes from 1h35min session.

b. Artefacts' repartition in the session

For further detailed results, we explore the distribution of the artefacts involved during the session.

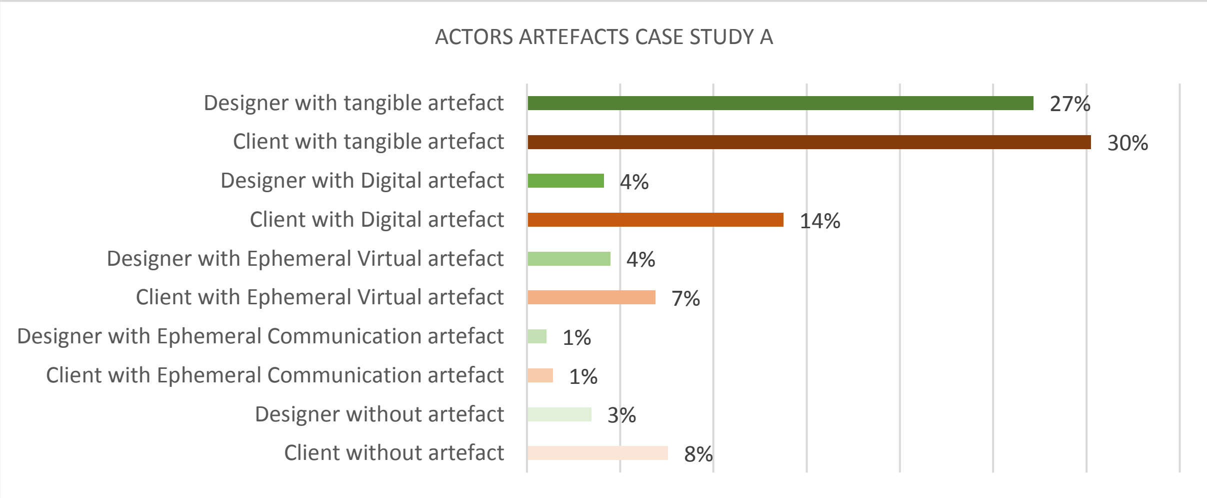


Figure 74. Distribution of artefacts used by actors in Case Study A

The graph Figure 74 shows clearly that the main artefact involved in this meeting is the tangible one. Both participants (27% from the designer and 30% for the client) use intensively the tangible representations.

However, the client (with 14%) uses a considerable amount of digital artefact. This remarkable use of digital artefacts by the client reflects the need for a digital tool, which was not planned to be used in this session. For case study A, the designers did not prepare any digital artefact to be used for discussion, therefore, when the client felt the need for a digital tool he compensates the absence of available ones by using his own smartphone and laptop. We can assume that only tangible representations were not sufficient to support exchange between participants.

Participants used virtual artefacts to support their speech with a relatively small percentage of the occurrences (7% for the client and 4% for the designer). Clients used more virtual artefacts than Designers may be because the client did not have the proper vocabulary to express his ideas contrary to the designers. Finally, with an equally small portion, only 1% for each participant, client and designers used communication gestures while talking. This is a relatively small amount, suggesting may be that the focus on the design task and the other artefacts were sufficient communication channels.

c. Temporal evolution of artefacts during the session

All these artefacts can be considered as the main instrument helping the exchange between participants during their meeting. An overview of the artefacts' evolution on the entire case study A session is presented through the following graph:

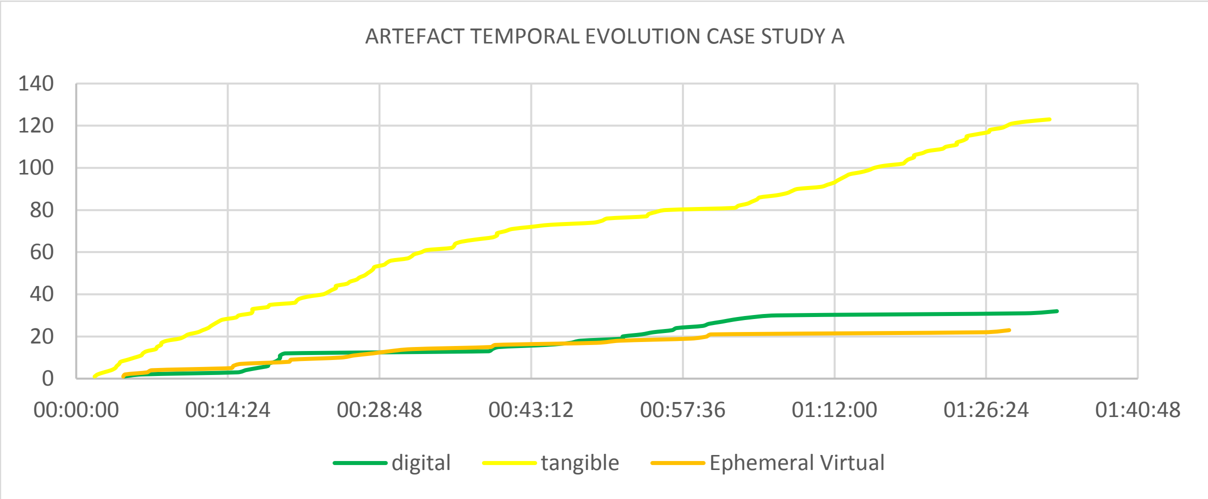


Figure 75. Temporal Evolution of artefacts in Case Study A

In accordance with the results from the actors-artefacts graph, this figure 75 characterizes the session with an important involvement of tangible design representation associated to a remarkable increase comparing to the digital and virtual artefacts. Both of them were modestly used on the entire session with a low rate of evolution. The set of the meeting room with nine barbeques and many printed designs of barbeques can incite the participants to more express their ideas using the tangible design representations. Despite that, we cannot deny that digital tool and the gestures in the air still represent a significant amount of interactions: if participants fail to find a proper available medium to express their opinion, they may look for a new one (their laptop) or try to use gestures in the air which still a good option for them.

2. Profile of interactions modalities:

a. Repartition of interactions modalities:

In the following paragraph, we will analyse our results with the second level of our analysis framework, which is "modalities of interactions". Interaction modalities are namely: Manipulating, Pointing, Viewing, Gesturing. We will try to understand through which modality the participants prefer to interact more:

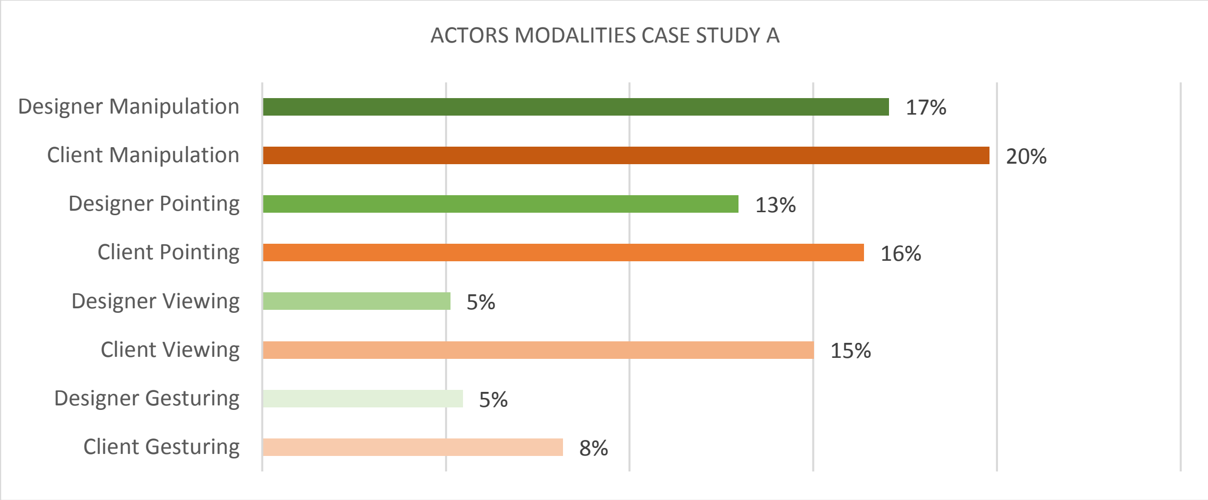


Figure 76.Distribution of interactions modalities in Case Study A

The graph illustrates that the manipulation of artefacts (37%) which includes holding, modification, annotating and sketching on prototypes is the most common way to interact with design representation for both participants, designer (17%) and client (20%). This can be explained again by the layout of the session room where the participants move around nine barbeques to manipulate and test the prototypes. In addition, referring to an artefact through pointing modality is well-used also with 16% for the client and 13% for the designer. Discussion with only gazing the artefact is more used by the client (15%) than by the designer (5%). We observe a low rate of gesturing; only between 5-8%.

b. Evolution of interactions modalities during the session:

The evolution of these modalities on the total time of the session can be represented by this graph:

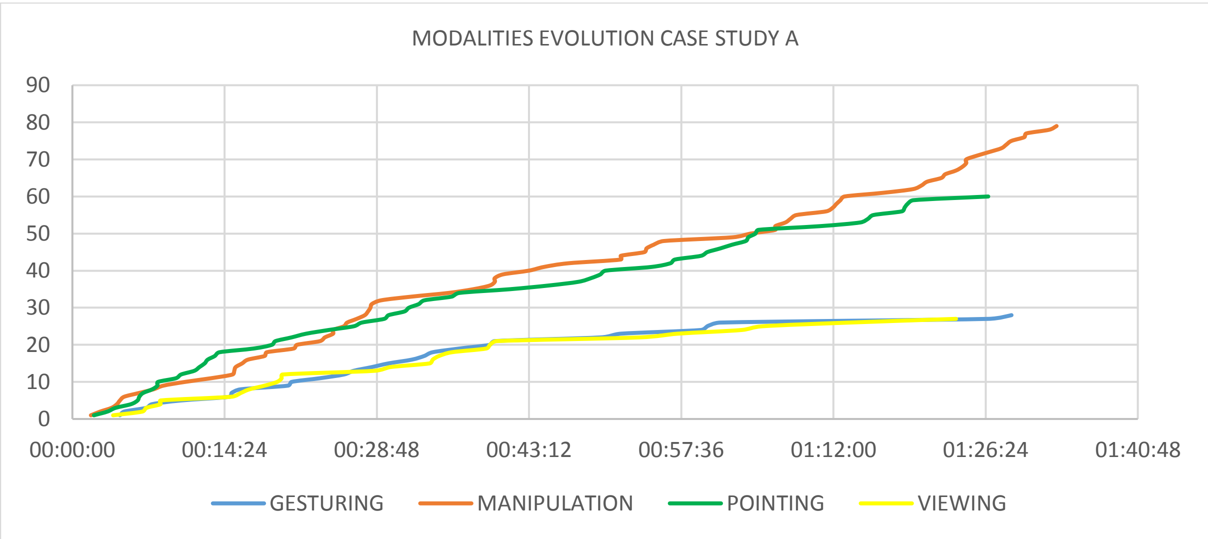


Figure 77.Evolution of interactions modalities in Case Study A

The pointing modality is preferred in the beginning of the meeting with a high rate of evolution then let the place to the manipulation once the actors get familiar with their session environment. In the presence of multiple physical mock-ups and prototypes, participants tend to touch more, annotate and sketch while discussing. Therefore, the manipulation category is the most used for the case study A. The evolution of viewing and gesturing modalities follow approximately the same curve with a low rate of increase and time limitation, these modalities are not used any more even before the end of the session.

3. Combination of interactions modalities and artefacts:

In this paragraph, we will draw a global overview of the session with both levels of the framework: the first level is the analysis of artefacts involved and the second one is the modalities interactions used. We will try to understand which actor uses which kind of artefact and through which modality during the entire session time:

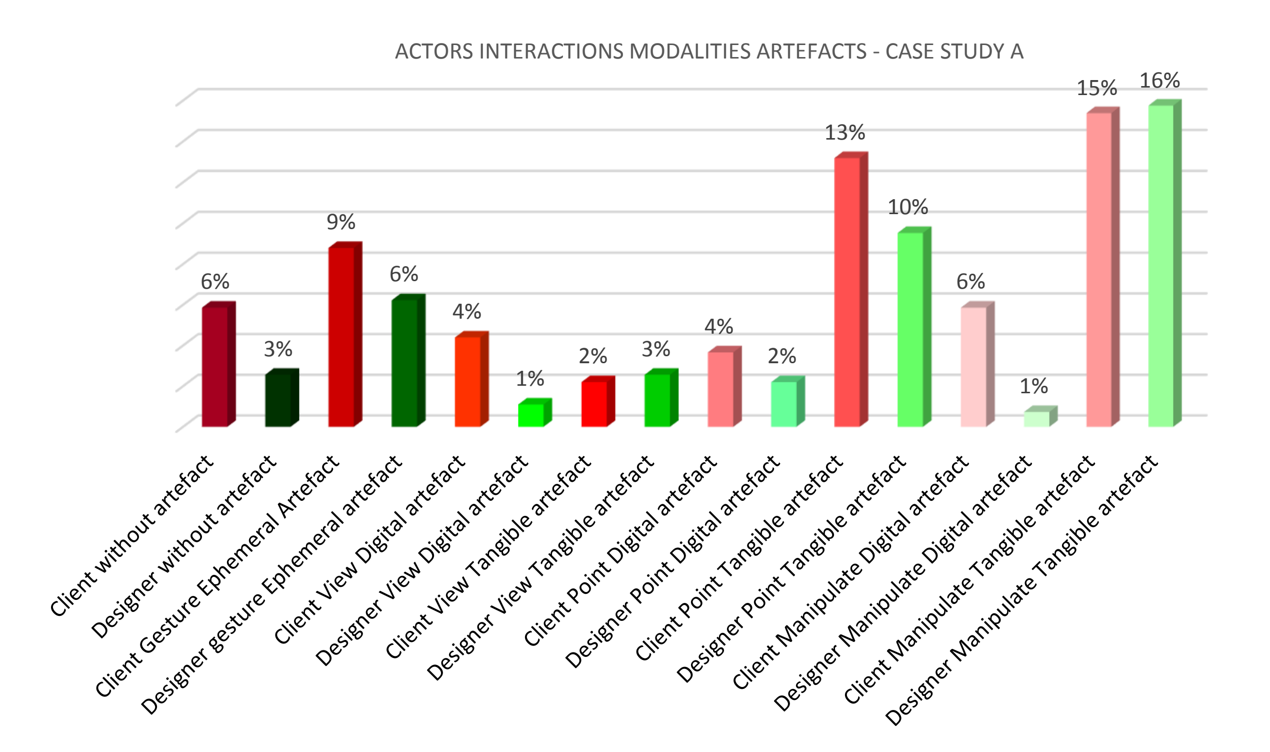
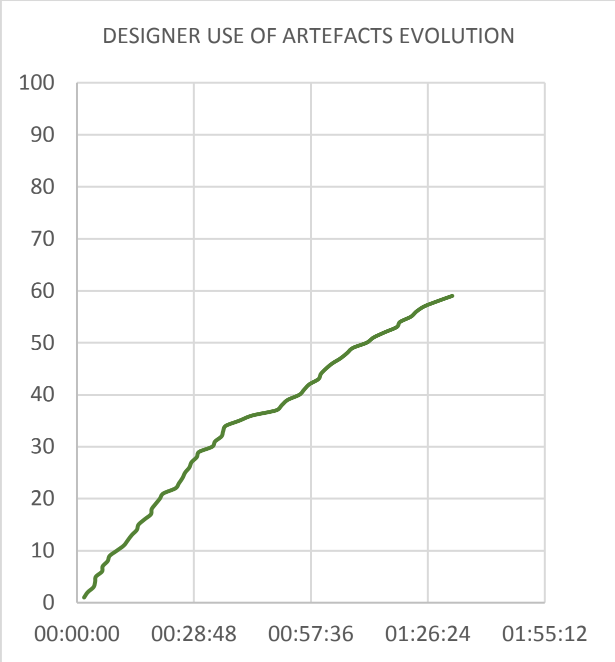


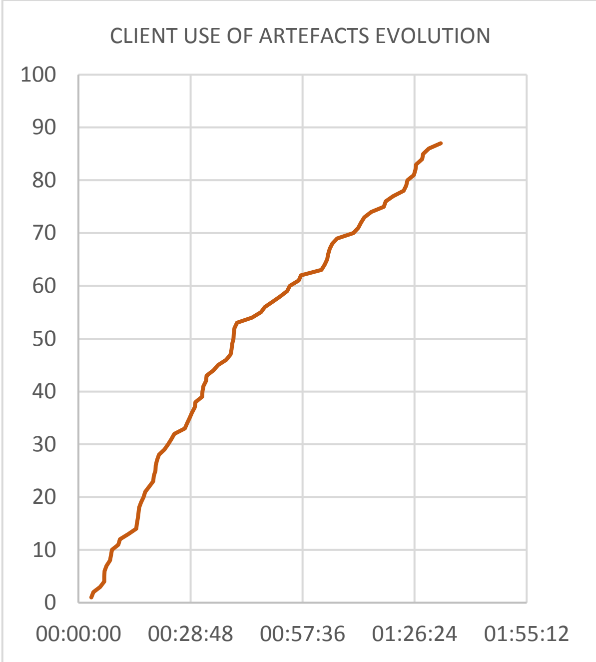
Figure 78.Combination of interactions modalities and artefacts in Case Study A

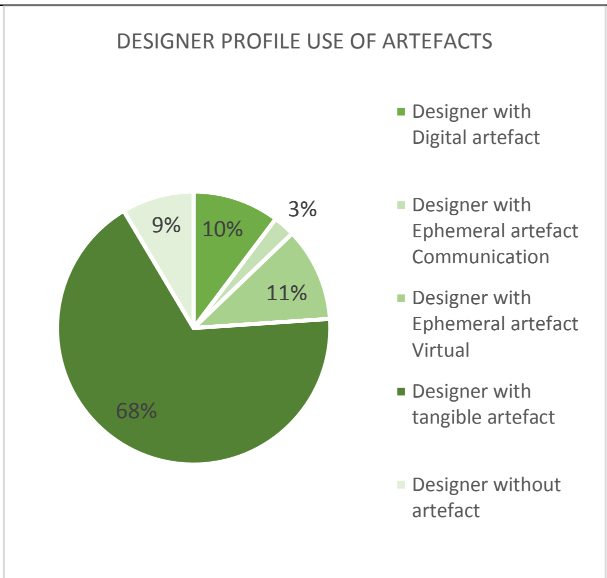
The combinatory illustration of the two levels of coding confirm the results of the previous graphs figure 78. The most privileged artefact used is the tangible design representation associated to the modality of manipulation for all the participants. Both designers and their clients prefer to interact with tangible artefacts first with manipulation (16% for designer, 15% for client) and then with inferior percentage through pointing at them (13% for client and 10% for designer). The third most important combination is gesturing through ephemeral artefact; gestures in the air help both actors to support their speech (9% for client and 6% for designer). The rate of use of digital artefact is more important for the client (6% of manipulation, 4% of pointing and 2% viewing) since the laptop involved in the session belongs to the client, this can explain the very low rate of Designer's involvement of digital (between 2-1%).

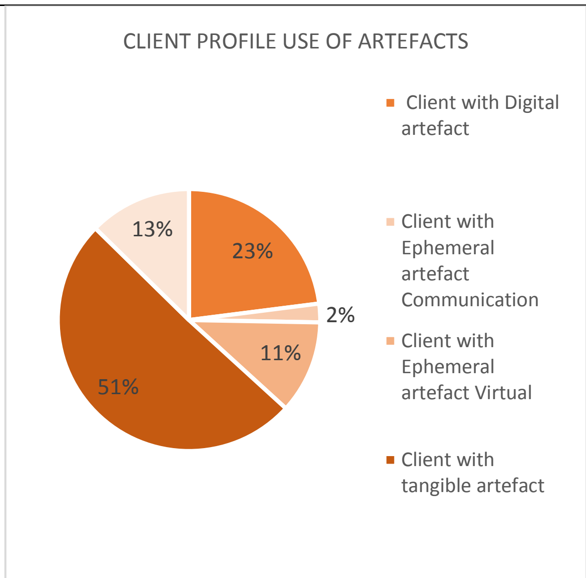
4. Profile of participants:

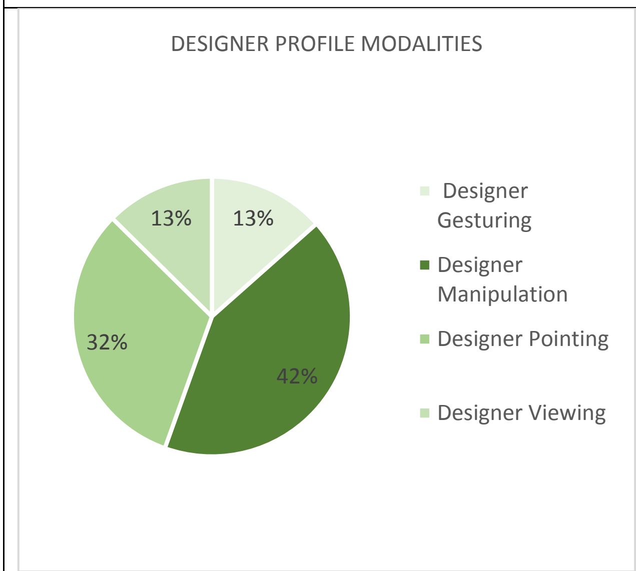
In this section, we will draw a profile for each session participant. In order to understand who is the most active member and through which artefact and modality he conveys better his needs and opinions. Case study A session involves two designers and one client. Table 9 below displays their profile during this meeting presenting their evolution in terms of use of artefacts, then the most used artefact and the most employed modality of interaction.


DESIGNER USE OF ARTEFACTS EVOLUTION
100
90
80
70
60
50
40
30
20
10
0
00:00:00
00:28:48
00:57:36
01:26:24
01:55:12


CLIENT USE OF ARTEFACTS EVOLUTION
100
90
80
70
60
50
40
30
20
10
0
00:00:00
00:28:48
00:57:36
01:26:24
01:55:12


DESIGNER PROFILE USE OF ARTEFACTS
9%
10%
3%
11%
68%
Designer with Digital artefact
Designer with Ephemeral artefact Communication
Designer with Ephemeral artefact Virtual
Designer with tangible artefact
Designer without artefact


CLIENT PROFILE USE OF ARTEFACTS
13%
23%
2%
11%
51%
Client with Digital artefact
Client with Ephemeral artefact Communication
Client with Ephemeral artefact Virtual
Client with tangible artefact


DESIGNER PROFILE MODALITIES
13%
13%
32%
42%
Designer Gesturing
Designer Manipulation
Designer Pointing
Designer Viewing

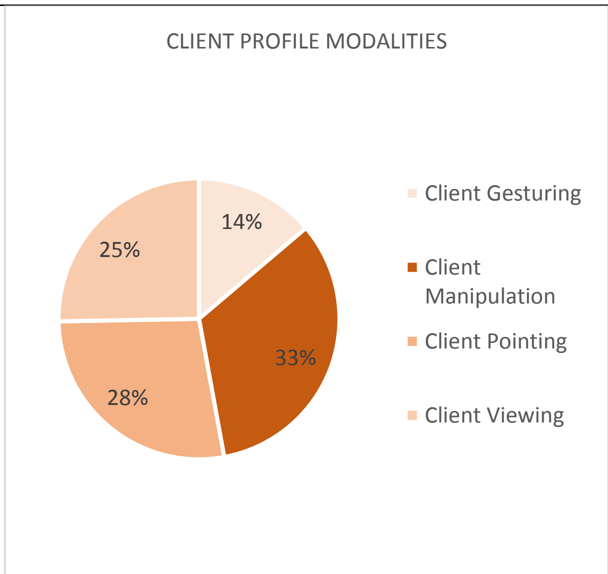

CLIENT PROFILE MODALITIES
25%
14%
33%
28%
Client Gesturing
Client Manipulation
Client Pointing
Client Viewing

Table 9.Detailed profiles of participants in Case Study A

The profile of artefact used highlights the crucial role of the client. The client is significantly more active than the designer is: he involved more than 90 interactions comparing to only 60 interactions from the designer side.

The respective profiles show variations: they approximately involve the same repartition of interaction rate with tangible (68%, 51%), an important difference in digital use (10%, 23%) and ephemeral artefacts are quite similar (14%, 12%).

Their modalities' profiles are quite similar with a majority of manipulation, a fair rate of pointing then small parts of gesturing and viewing. The difference is spotted in the evolution of each actor during the total time of the session. The client presents an interesting curve that illustrates the constancy of his contributions during the meeting.

B. Case study B

The second case study is about the satellite-tracking device. The aim of the meeting is a final refinement for first generation product, including user interaction, colour, material, finish, and technical requirements. Their project is about creating a model with high level of detail and accuracy.

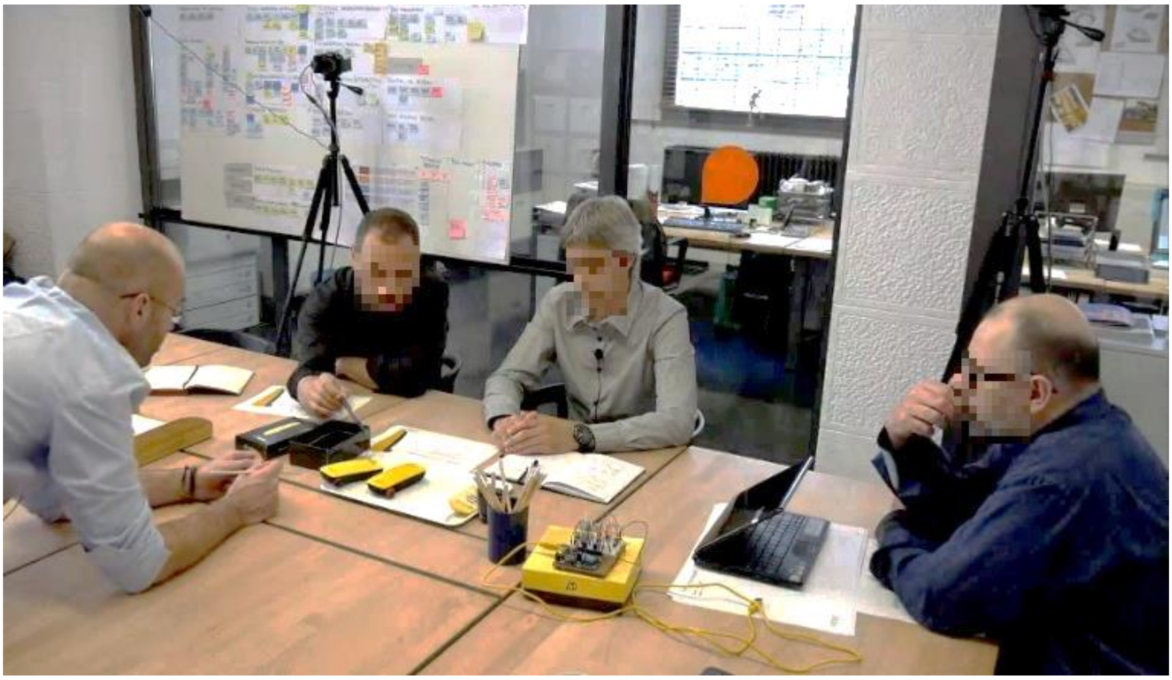


Figure 79.Illustration of Case Study B

During this meeting, three designers from design agency received the client at their premises. The client is the head of the communication department. The meeting room was equipped by three satellite-tracking devices with different colours and designs associated to an electronic device to test the leds. The plan was to evaluate the three suggestions and to select one of them as a final solution.

1. Profile of artefacts

a. Place of artefacts in the session:

As in case A, here artefacts support a very important percentage of 91% of the total time of session. Only 9% of discussion is set without any reference to artefacts; which means that only 6 minutes from 1h22 minutes does not involve design representations.

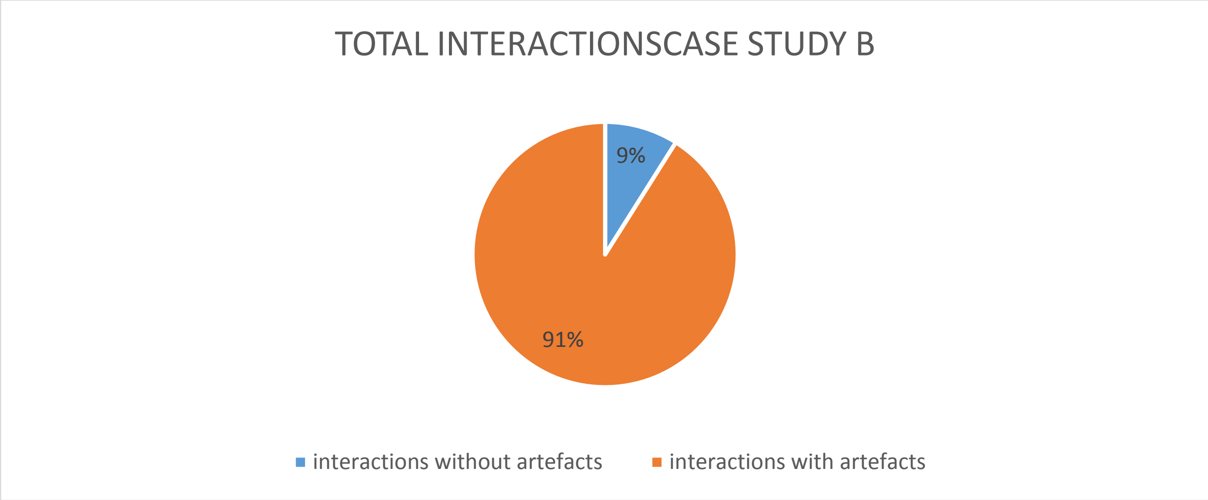


Figure 80. Total number of interactions in Case Study B

b. Artefacts' repartition in the session

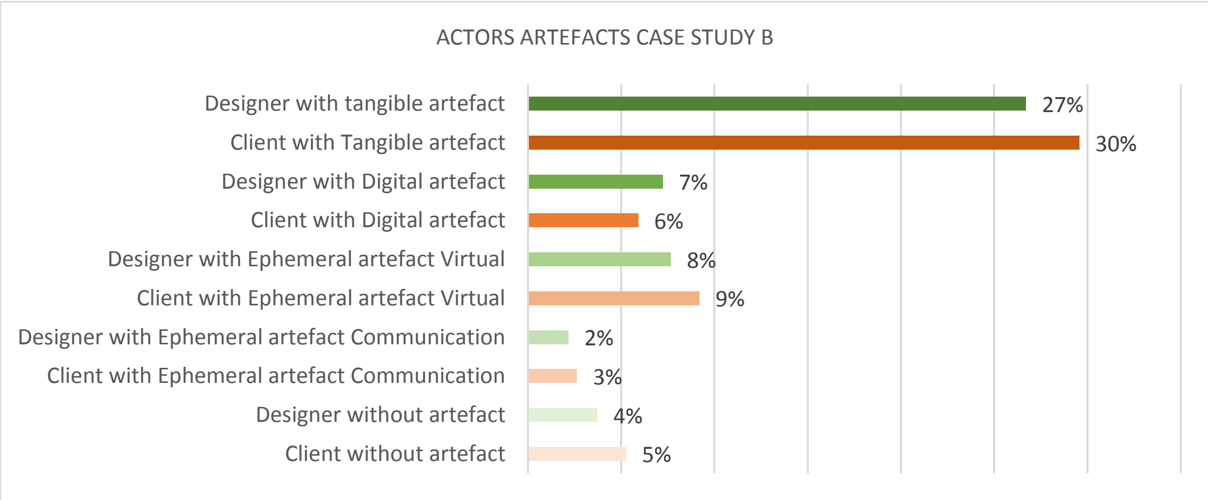


Figure 81. Distribution of artefacts used in Case Study B

The graph highlights an important percentage of tangible artefact used during the case study B session. Both participants (27% from the designer and 30% for the client) use the tangible design representations. Simulation of shapes through gestures, and mimicking hands functionalities represents 9% from client and 8% from designer. The digital representations have been only manipulated with 7% from designer and 6% from the client. Finally, with a very small percentage, only 2 and 3%, designers and client use gesture to support oral communication.

c. Evolution of artefacts during the session

The following graph draws the evolution of each artefact during case study B session:

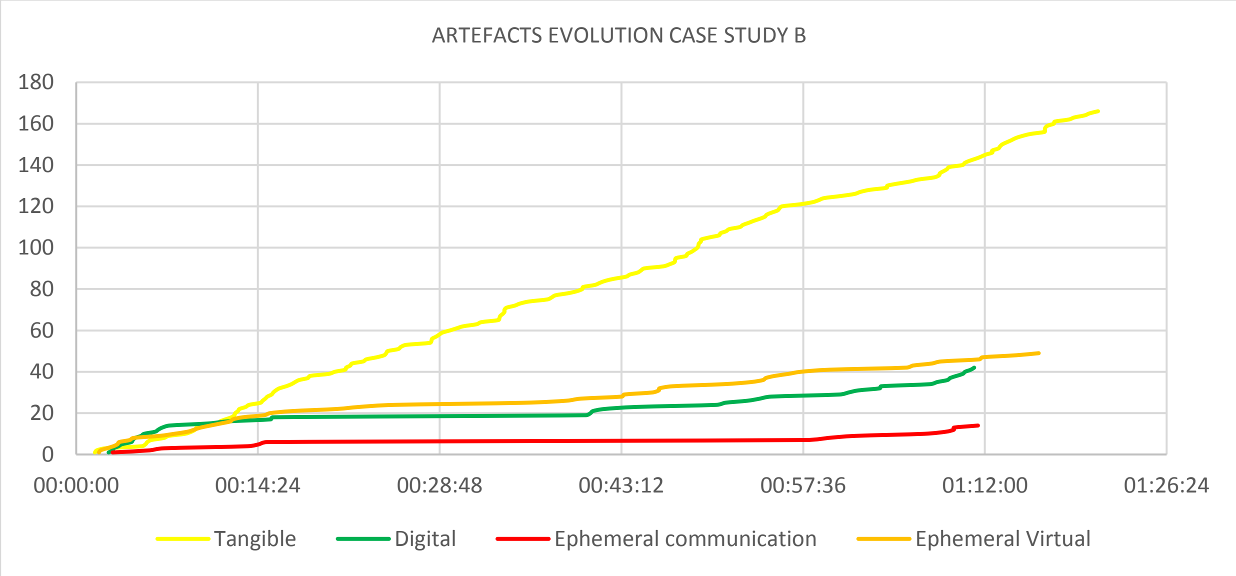


Figure 82.Evolution of artefacts in Case study B

The difference of evolution between tangible artefacts and the others is quite remarkable. The session is characterized by a predominance of tangible design representation, a very low and time limited use for ephemeral communication artefacts. Then we can spot a quite similar profile evolution of digital artefacts and ephemeral virtual but still less important than the main artefact. Participants were dealing with three 3D printed mock-ups presented as suggestions of a potential solution. This context can explain that the session was running around these tangible mock-ups but still implied the need for other tools like digital ones and gestures in the air.

2. Profile of modalities

a. Repartition of modalities

The second level of our analysis framework considers analysing the collaborative design session from the modalities of interaction point of view, the analysis bring the following results:

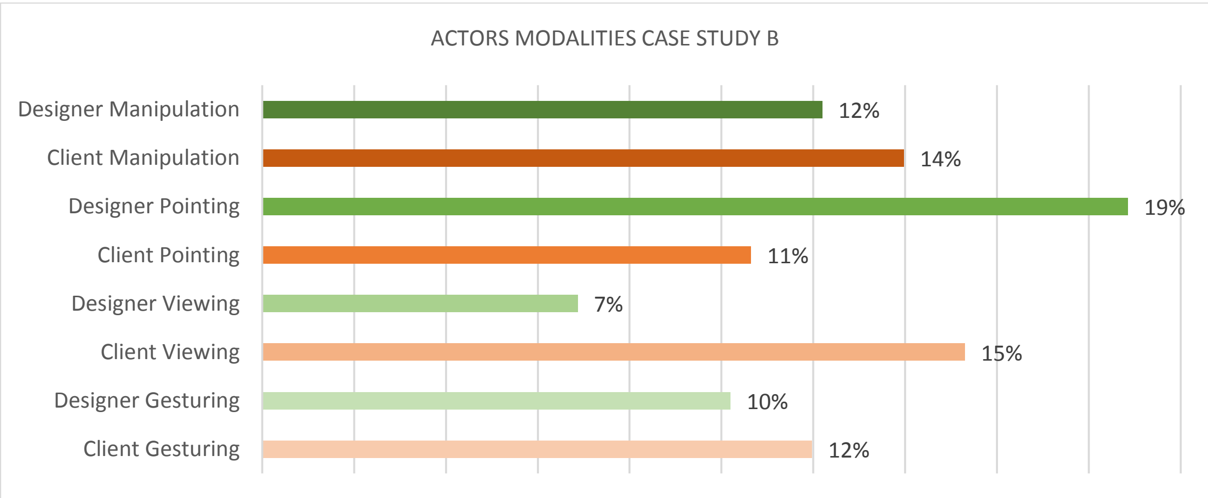


Figure 83.Distribution of interactions modalities in Case Study B

For this case study, the pointing modality presents the most important percentage with 30%, 19% initiated by the designer. The client prefers to interact more with viewing the object (15%) while the designer only used a limited rate of viewing (7%). The layout of the session room displayed the three proposals at the center of the discussion table, which may explain the important percentage of designers pointing and client gazing. The majority of the discussion occurred around these prototypes. Manipulation of the artefacts is the second most preferred modalities for both actors with 14% for client and 12% for designer. A very close rate of gesturing is recorded for each one 12% for client and 10% for the designer.

b. Evolution of artefacts

The following graph illustrate the evolution of modalities of interactions used during the case study B session:

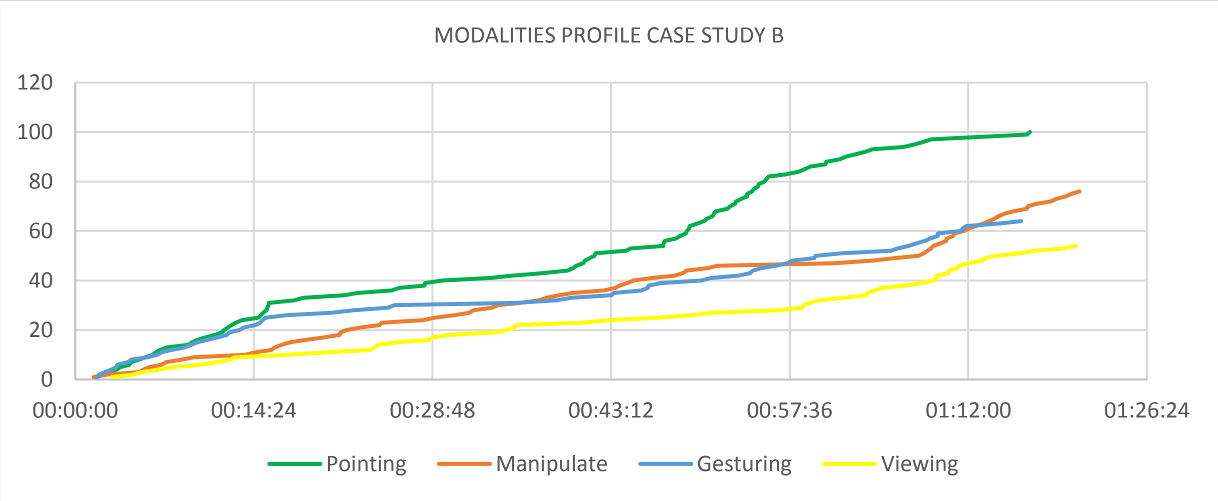
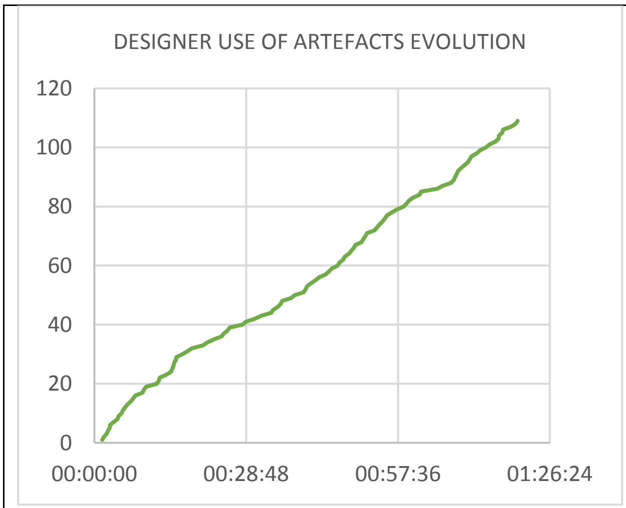


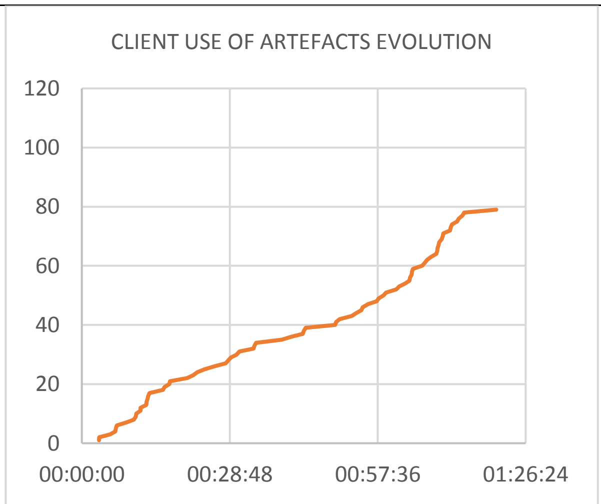
Figure 84.Evolution of interactions modalities in Case Study B

Drawing the profile of pointing modality clearly demonstrates its important evolution during the total session time with a noticeable difference comparing to the rest of modalities. Gesturing manifests a good evolution start at the beginning of the session then decrease so the manipulation of artefacts take the second place for the most employed modalities. Viewing presents the lower profile increase in case study B session.

3. Profile of participants

In this section, and for each actor's category participating in the session, we will plot his profile. This profile can give a detailed description of each actor's involvement. The case study B session involves three designers and one client below we draw their profile during this meeting presenting their evolution in terms of use of artefacts, then the most used artefact and the most employed modality of interaction:





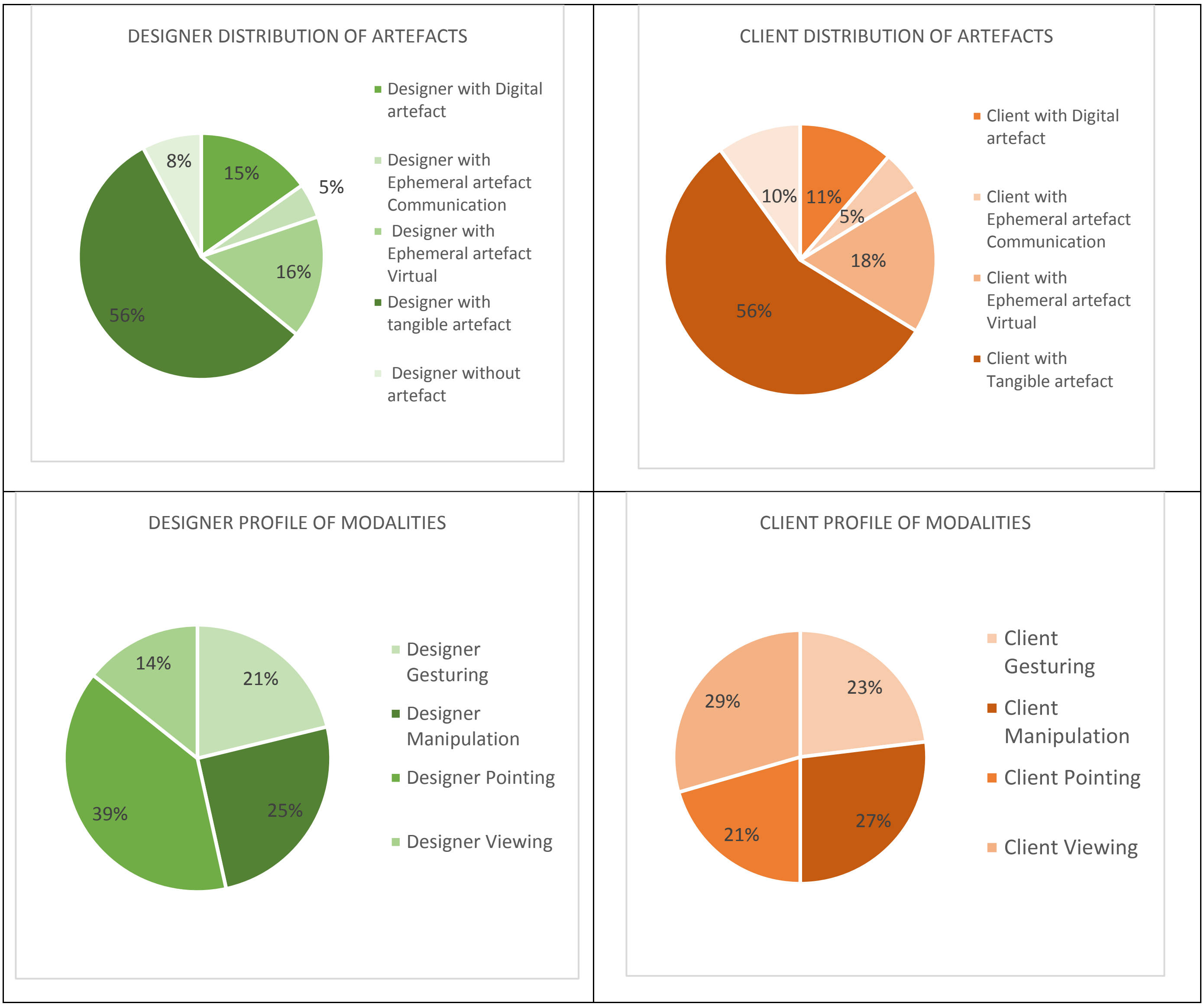


Table 10.Detailed profiles of participants in Case Study B

The distribution above illustrates a profile of artefacts involved and modalities used is very similar for the two actors. The repartition of artefacts is approximately the same. However, the evolution during the total session time presents a big difference between designer's profile and client's one. The cumulative use of artefacts favours the designer's profile to be the most active one. The client manifests a good amount of contribution.

In terms of artefacts repartition, both actors present a similar interest to tangible artefacts with 56% of their total time using these design representations. Then it is the same case for the second preferred artefact which is ephemeral virtual with 18% for client and 16% for designer. The two distribution of modalities present a similar proportion of repartition with an interest of designer in pointing with 39% of his total time and 29% of total client time spent on viewing artefacts. These results can be explained by the nature of the session where designers lead, present and explain their prepared suggestion to their client. The two actors have a similar second privileged modality, which is manipulation: 27% for client and 25% for the designer.

C. Case study C:

For this case study, we will be reproducing faithfully the usual running of collaborative design sessions that were captured in the partner premises. The aim of this reproduction is to evaluate the rate of change when we move designers from their standard place of work and change their design partner from clients to end-users. In order to increase similarities and minimise the differences, we will select case studies that are as close as possible to the observation in Design Company in terms of task, actors and duration. For this observation section, we present the reproduction of case study C session in our Grenoble INP lab.

Figure 85.Illustration of Case Study C

This condition was run again with the hand held device for communicating user location in emergency (idem case study B). The overall aim was that designers define together with end-users the colours, materials and finish of the main packaging for specific environments like the mountains. They also provide to define the location and pattern of LED status lights. The meeting involved one designer from Design Company and three potential end-users (2 engineering design students and 1 administrative staff).

1. Profile of artefacts

a. Place of artefacts in the session

Again the analysis under Transana confirms again that the artefacts play a key role in the co-creation design session. The following breakdown illustrates this principal role and shows that 96% of the session was supported by various types of artefacts.

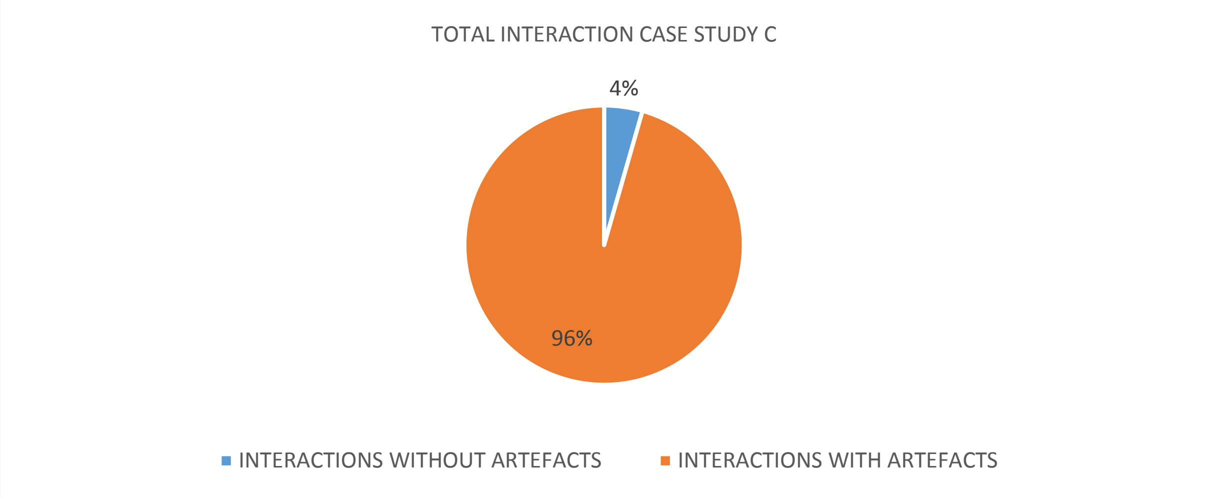


Figure 86. Total number of interactions in Case Study C

b. Artefacts' repartition in the session:

For this standard session, the designer is clearly dominating the session with majority of interactions. The most involved artefact is the digital one with 31% from the designer side. The designer also involves tangible artefact and ephemeral ones with important percentage 25% and 24%. The interactions initiated by the end-users are balanced between tangible, digital, and very limited for all types of artefacts (5%). The session case study C is characterised by a predominance of digital artefact use. Participants still involve fair amount of tangible and ephemeral artefacts. We underline the limited rate of end-users participation in this meeting. They contribute with only 16% of total session interactions.

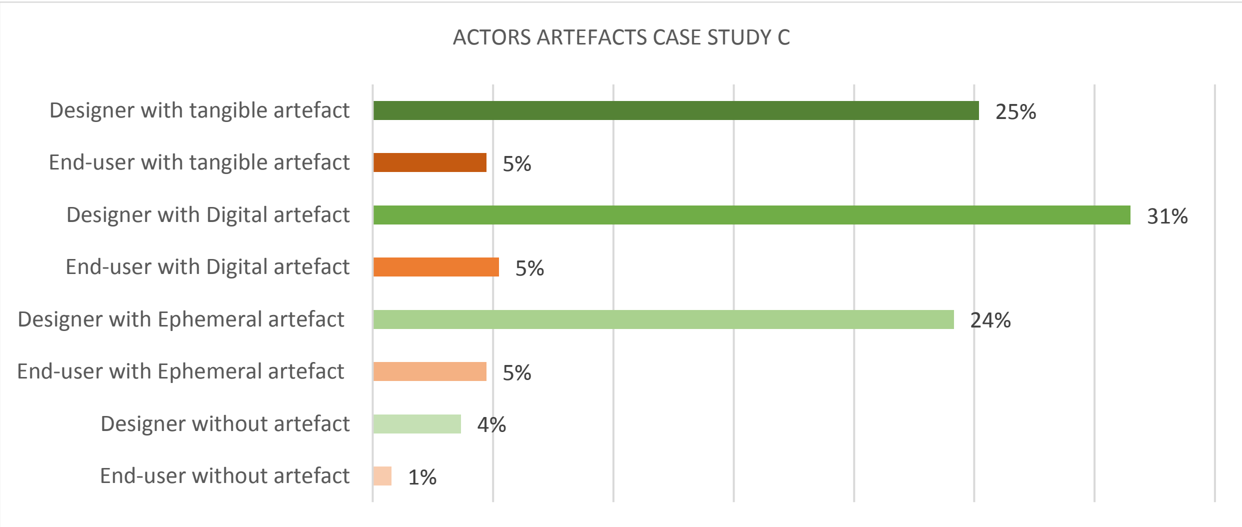


Figure 87.Distribution of artefacts used in Case Study C

c. Evolution of artefacts during the session:

The case study C session in controlled lab condition has three phases:

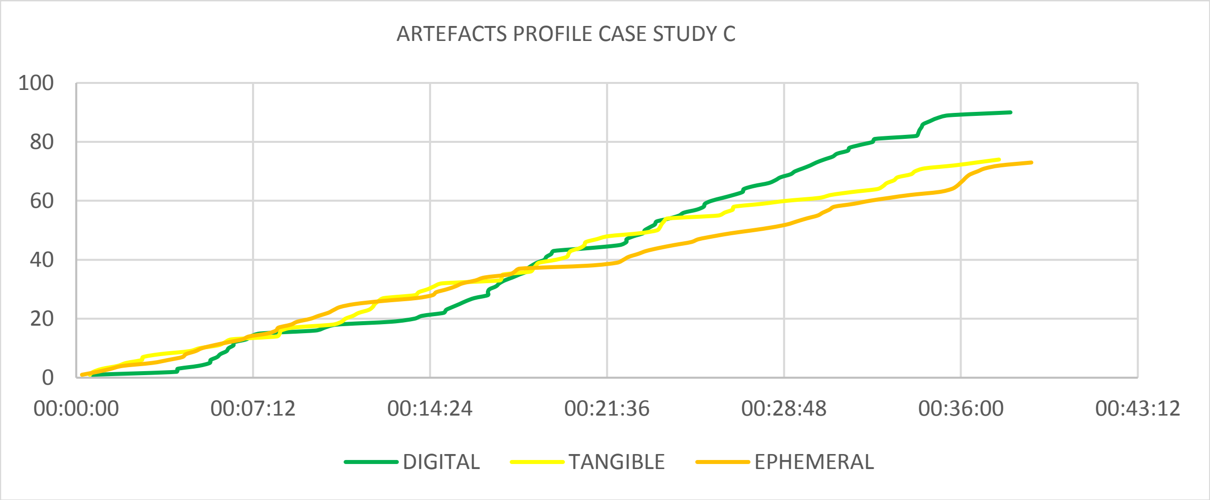


Figure 88.Evolution of artefacts in Case Study C

The first seven minutes were dedicated to the presentation of the meeting agenda. To support this phase, participants and more precisely the designer prefers to interact with tangible design representations. Then the discussion is supported more by the ephemeral artefact for the next seven minutes. The last phase of the session was characterised by a high rate of digital artefacts and a remarkable decrease of tangible prototypes use and especially ephemeral gestures. Unlike other standard meeting, case study C manifests an important involvement of digital artefacts. Participants privilege to interact more with digital representations of the product displayed on large TV screen rather than manipulating the tangible prototypes available on the discussion table.

2. Profile of modalities

a. Repartition of interactions modalities

To have a complete overview of this session, we present the results of the second level of coding concerning the modalities of interactions employed:

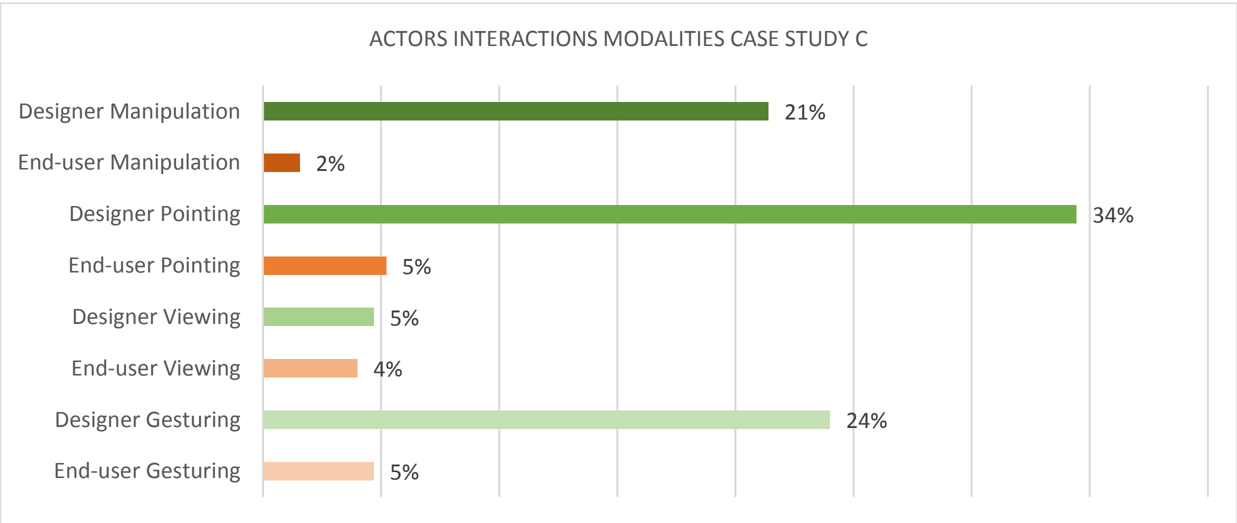


Figure 89.Distribution of interactions modalities in Case Study C

The graph Figure 89 highlights the important amount of pointing modalities about 39% especially used by designer with 34% of the whole session time and 5% from the end-user. Designer also involve a high rate of gesturing 24% and 21% of manipulation modality, which brings a total amount of gesturing in the session to 29% and 23% of interactions. The view modality presents a low rate with only 9% between end-users and designer.

This graph highlights also the limited contribution rate of end-users up to only 5% per modality. These results are may be related to the nature of end users' profiles but this needs to be confirmed with other experiments. In term of modality of interaction, the graph stress that end-users present a very limited contribution. Comparing to real clients in case study A and B, end-users are less participative.

b. Evolution of modalities during the session

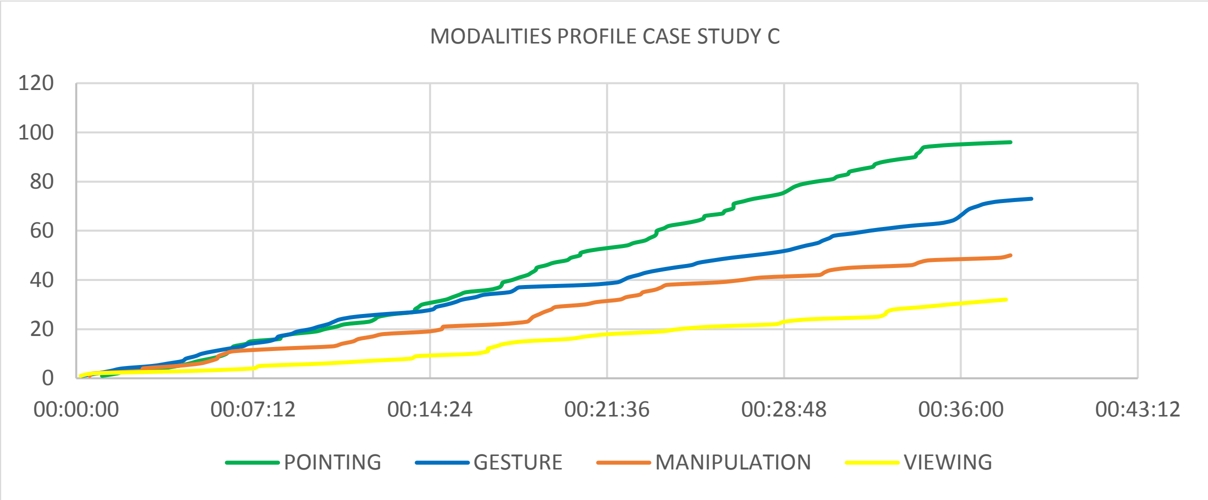


Figure 90.Evolution of interactions modalities in Case Study C

Figure 92, the modalities profiles confirm the previous results to spot the pointing as the main modality used for the session. The beginning of the session implies the different modalities then starting from the seventh minutes, right after the presentation of designer, the preferences of use tend to privilege the pointing and gesturing. We also can notice a significant evolution of gesture with a lower rate of manipulation and finally a very limited evolution of viewing.

3. Profile of participants

For this standard session, we present the profile of design actors during the session using the evolution of the artefacts they involve. The client's curve is very low comparing to the designer's one. This can be explained by the fact that we have end-users here instead of clients. This needs to be confirmed however.

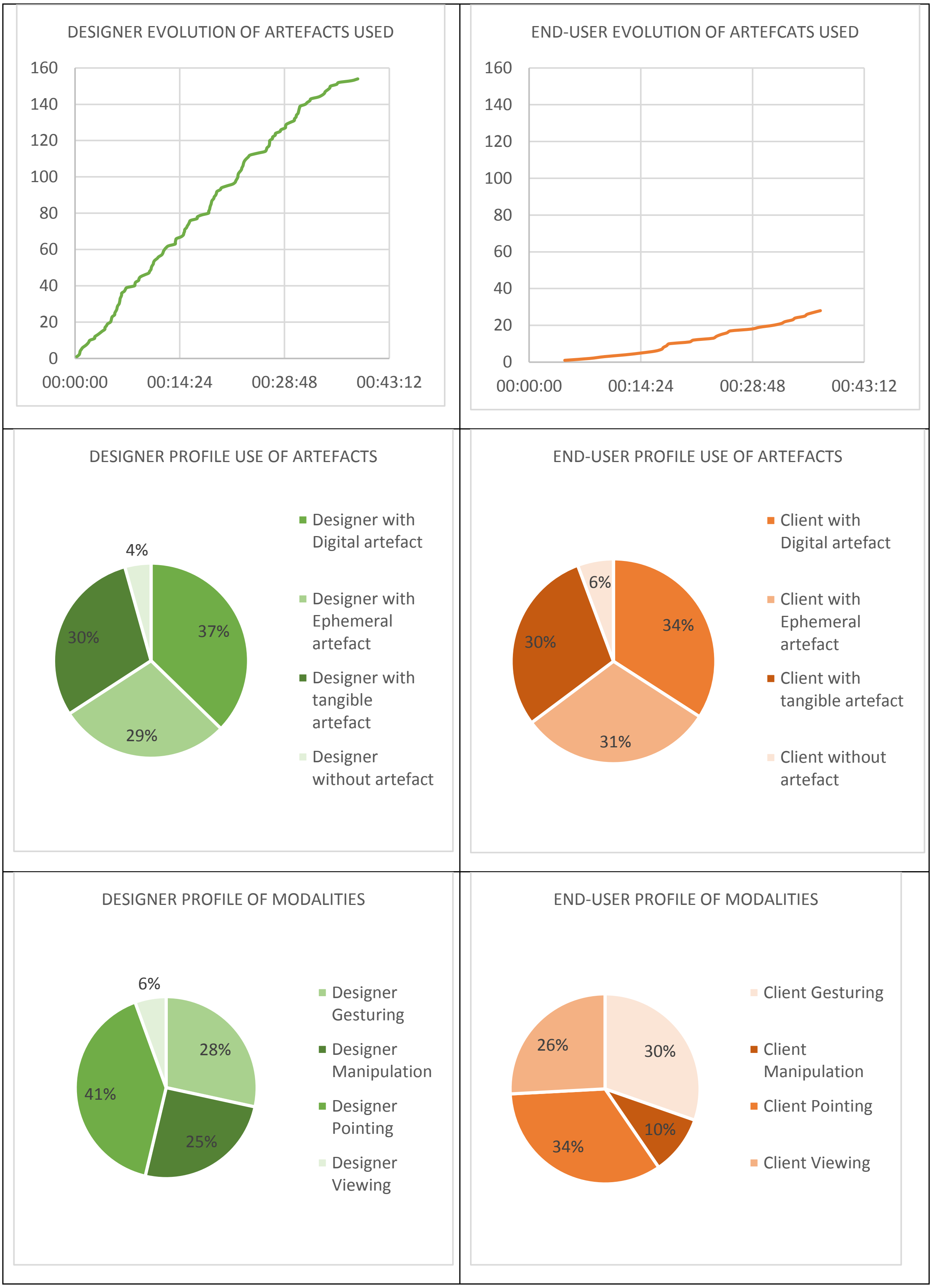


Table 11.Detailed profiles of participants in Case Study C

The difference is spotted in the evolution of each actor during the total time of the session. The designer presents an interesting curve that illustrates the increase of his contributions during the meeting. End-user present a very limited contribution in the session discussion at least in terms of volume of interaction.

The profiles reflect many common points between designer and end-users: they approximately involve the same repartition of interaction rate with digital (37%, 34%), an equal rate of tangible use (30%) and ephemeral artefacts are quite similar (29%, 31%) of their own time. This regardless the total amount of interactions, which is very different as first graphs of table 11 show.

Their modalities' profiles repartition is quite different with a majority of pointing 41% and 34%, a fair rate of gesturing 28% vs. 30% for the end-users. A small part of viewing for the designer and a small amount of manipulation for the end-users. This corroborates the apparent low involvement of the end-users compared to the clients in the previous sections.

3. Analysis and discussion of the standard sessions

Based on the literature, we investigate the role that design artefacts play in collaborative design session. Design artefacts play a pivotal role in supporting communication and coordination between co-designers(Vyas, van der Veer, & Nijholt, 2013)

1. First hypothesis:

Therefore, we formulate the first hypothesis as follows:

H1: Investigating the time design practitioners spent using artefacts during a collaborative design session demonstrates the important place of artefacts. Therefore, we can consider the artefacts as an interaction communication channel at the same level as verbal or gestures.

In order to confirm the first hypothesis, we will check out the parameter of time spent with artefacts during the collaborative design session.

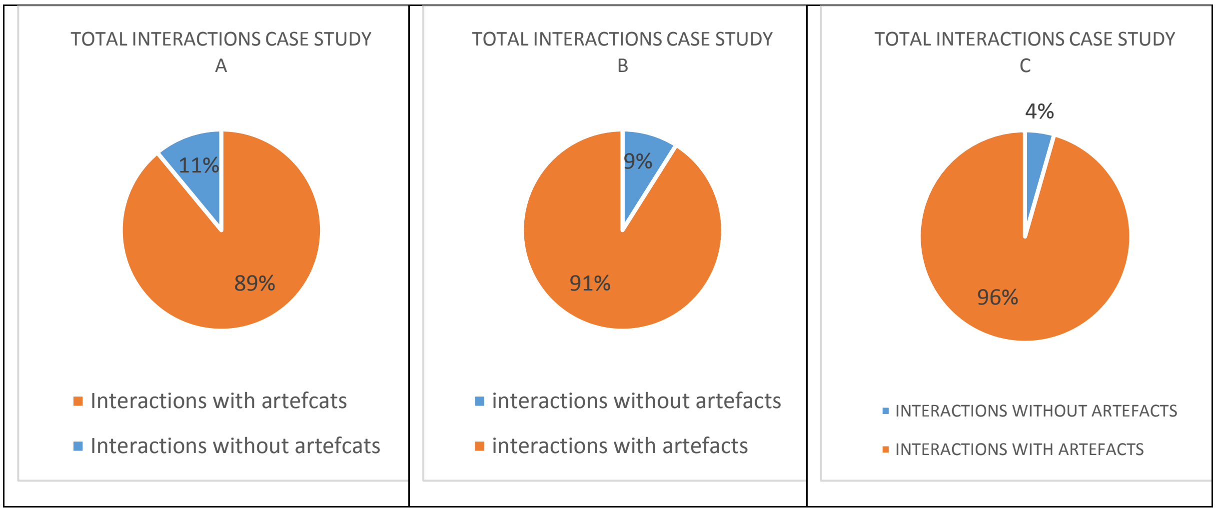


Table 12.Overview of total number of interactions in standard sessions

As the graphs show(Table 12), the time spent without artefact is limited to a small percentage up to 11%. For these standard situations, case study A session lasts 1h35 minutes, only 10 minutes was not supported by artefacts. For what concern case study B, which lasts 1h35minutes, design actors involve different design artefacts during 1h28 minutes. This means that only 7 minutes were not supported by artefacts. Finally, case study C session, which took place in a controlled environment at Grenoble INP lab and lasted 41 minutes, participants did not involve artefact only for 1 minute.

Regarding the important percentage of time involving artefacts, we can confirm that design actors rely on these artefacts to communicate their ideas and proposals. Design proposals evolutions are based on discussions through artefacts.

We can therefore confirm that despite the environment changing between different standards sessions, artefacts still play an important role manifested by a huge percentage of involvement during each meeting.

2. Second hypothesis:

The second hypothesis we worked on through the analysis of standard sessions comes from the question of involvement of external stakeholders (clients and/or end-users). We assume that encouraging the client and end-user to be involved in the design activity will have a valuable positive impact on design the process: the client has some knowledge and information that can efficiently contribute to the project. In addition, with a series of meetings and brainstorming will allow the exploration of the expected product functionalities. The active engagement of stakeholders will also help designers to better understand and address their needs during the project.

We can define end-users as people who come to a store mainly to buy the products or services provided. Customers or what we call client in our case are people who buy advice and solutions personalised to their particular needs(Christian Fisher, 2019). Therefore, by definition these profiles are different in term of needs and goals. We assume that involving them in the collaborative design task will influence the running of session.

H2: We assume that profile of stakeholders (Client or End-user) impact the rate of interaction: We suppose that clients interact more than end-users, since they are directly involved on their own project. Therefore, the interactions in session involving clients will be more dense and richer than when the session runs with end-users who are only potential target of the product.

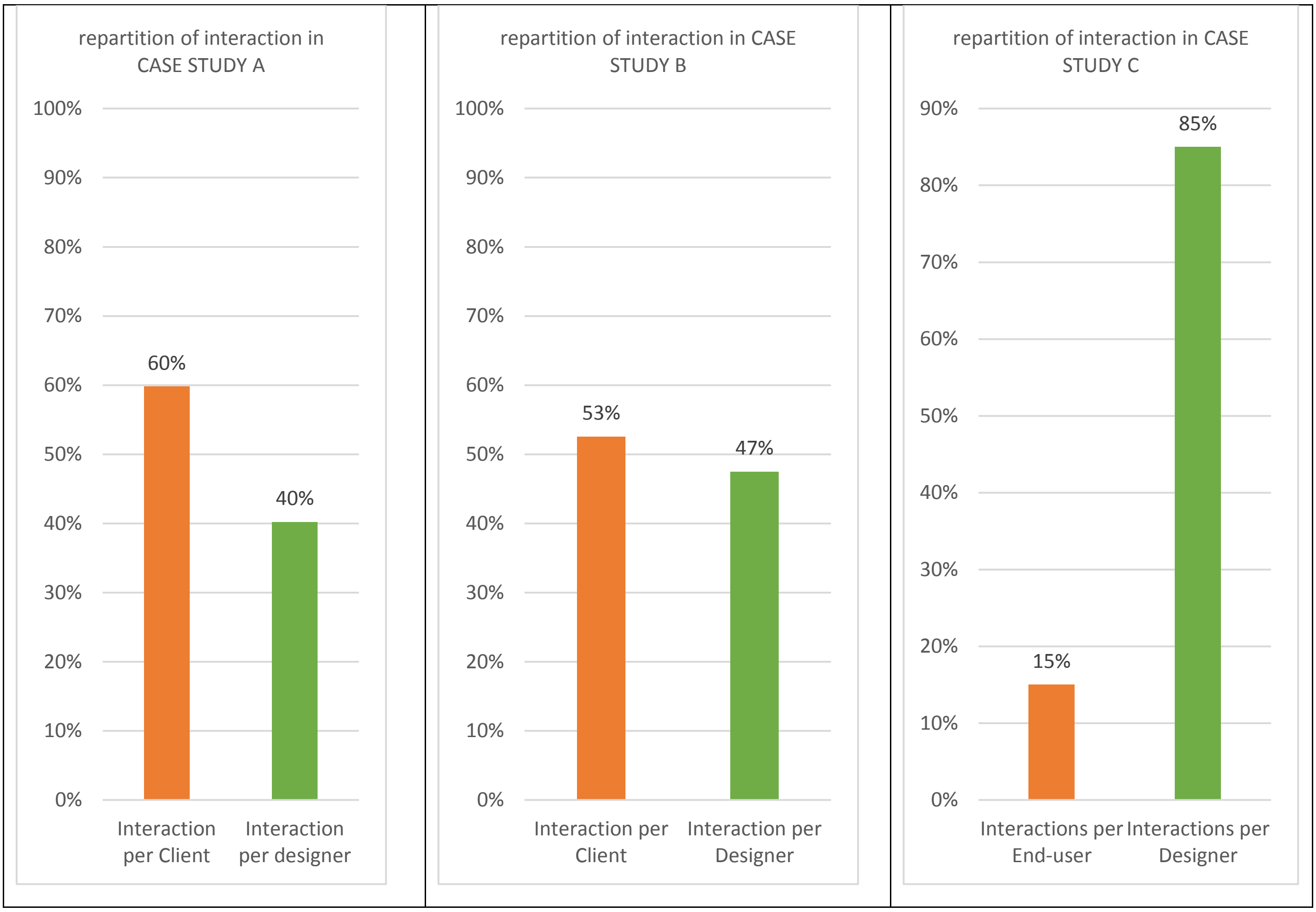


Table 13.Overview of interactions distribution in standard sessions

For this set of experiment, the implication of client profile is clearly different from the end-user. When the collaborative design meeting is involves a client of the design agency, his rate of participation is between 53% and up to 60%, which highlight the place and role he plays in the design activity. When the client contributes more than the designer does, this reflects a high level of implication and dedication for a successful design task. In contrast, the end-user presents a limited involvement profile with only 15% of participation in the session.

These results suggest that the difference of profile between client and end-user clearly influences their implication within the collaborative design activity. For a high performance collaborative session, these results encourage designers to incite their end-users to be more active in the design sessions and may organise different types of sessions. We will see later if the augmented reality environment has an effect on user's participation.

4. Findings:

To conclude the observation section of standard collaborative sessions, we will spot the most important findings:

1. Artefacts involvement in standard session

As presented in the first part of the chapter, the analysis of the three standard sessions shows that typically 90% of the interaction time involved the use of different types of design representation. Therefore, the artefacts play an important role in co-creative design session to enable participants communicate between each other and progress in the design process.

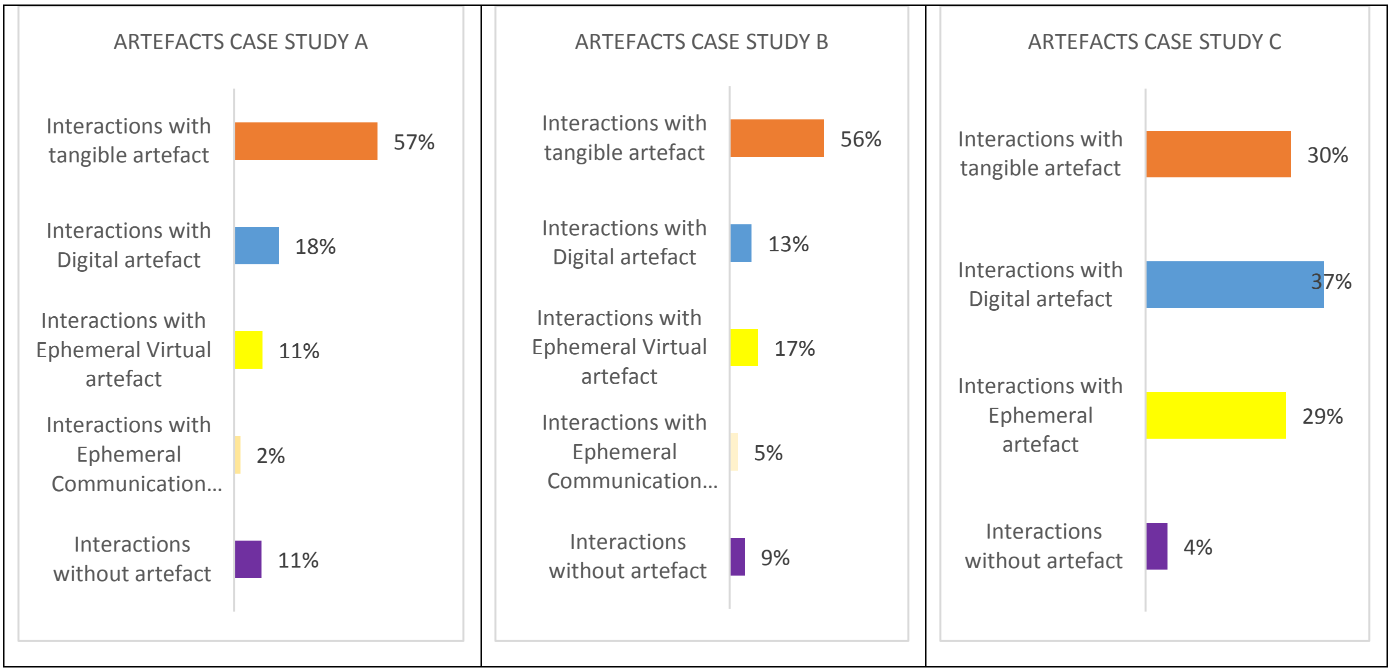


Table 14.Overview of artefacts distribution in standard sessions

In addition, the analysis concludes that both designers and clients interact with tangible artefacts 56%, 57% and 30% (notes on post-it, sketches on drawings or printed proposals, foam models, 3D printed prototypes etc.). They also use digital prototypes 18%, 13% and 37% (power point presentations, renderings or CAD models presented on a computer or TV monitor etc.). Although participants seem to prefer tangible design representations, especially in case study A and B, we notice that they involve a good percentage of ephemeral artefacts to express their needs. This is true particularly for case study C where end-users were involved (37%).

2. Interactions modalities involvement in standard session

For what concerns the interaction modalities, the three sessions present different profiles.

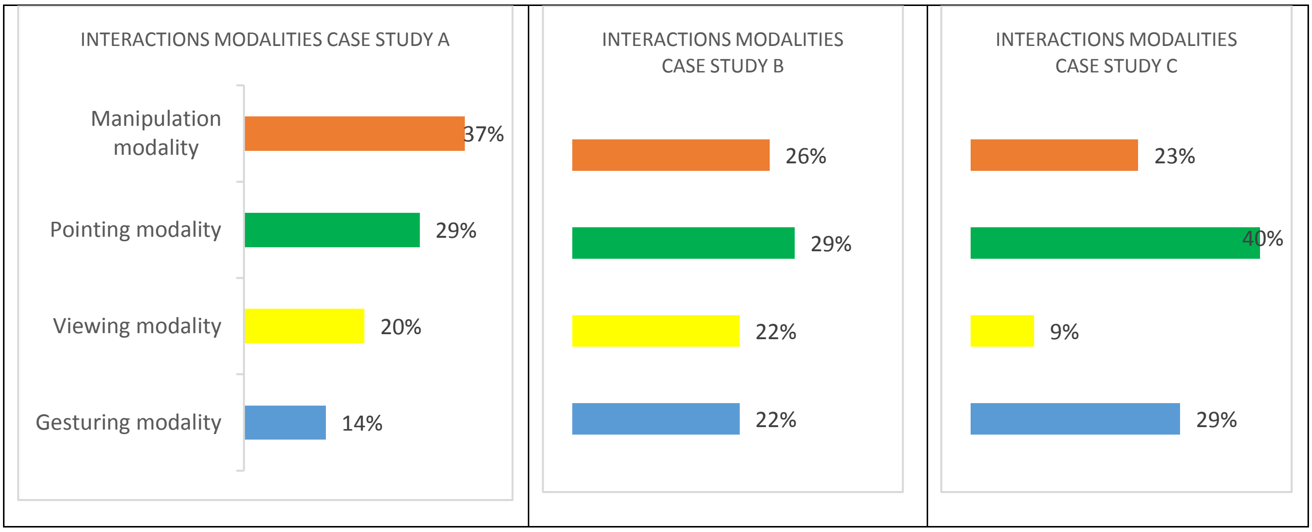


Table 15.Overview of interactions modalities distribution in standard sessions

Participants used shared modalities: pointing between 29% and 40%, viewing between 9% to 22% and finally gesturing between 14% and 29%. Besides, we notice an important rate of manipulation for all sessions: 37%, 26% and 23%.

3. Stakeholders' involvement in standard sessions

In this work, we have special interest for clients' or end-users' involvements. The following graph presents the rate of use of the main artefact in each session by the client (or end-user):

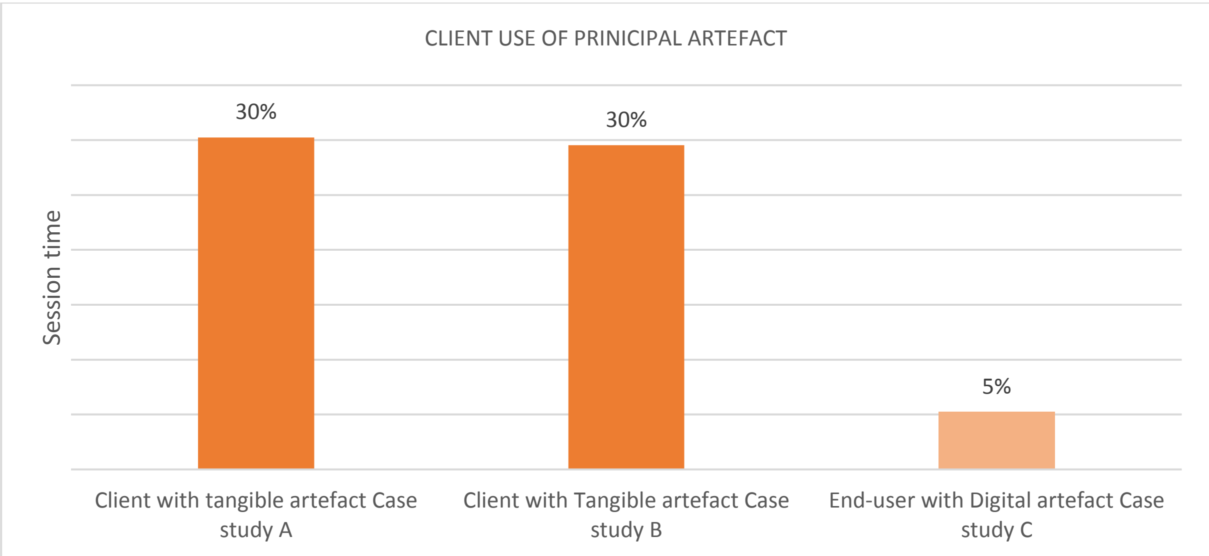


Figure 91.Overview of principal artefact involved by client in standard sessions

Case study A and B are similar in terms of client involvement with 30% of session total time, client is participating in the design discussion involving the tangible design representations. Case study C is completely different in term of favourite artefact first and then with a very low rate of end-users' implication: the participation of end-users is limited to only 5% of digital artefact use. These findings confirm our second hypothesis, supposing that the profile of stakeholder affects his rate of participation; when clients are implied in the design task they show more interest manifested by a high rate of interactions sometimes even more than designers do. The hypothesis is verified by the findings presented on this graph: 30% rate of client participation vs. 5% of end-user involvement.

4. Artefacts evolution in standard sessions:

Through the following graph, we present the evolution of artefact in three standard case studies.

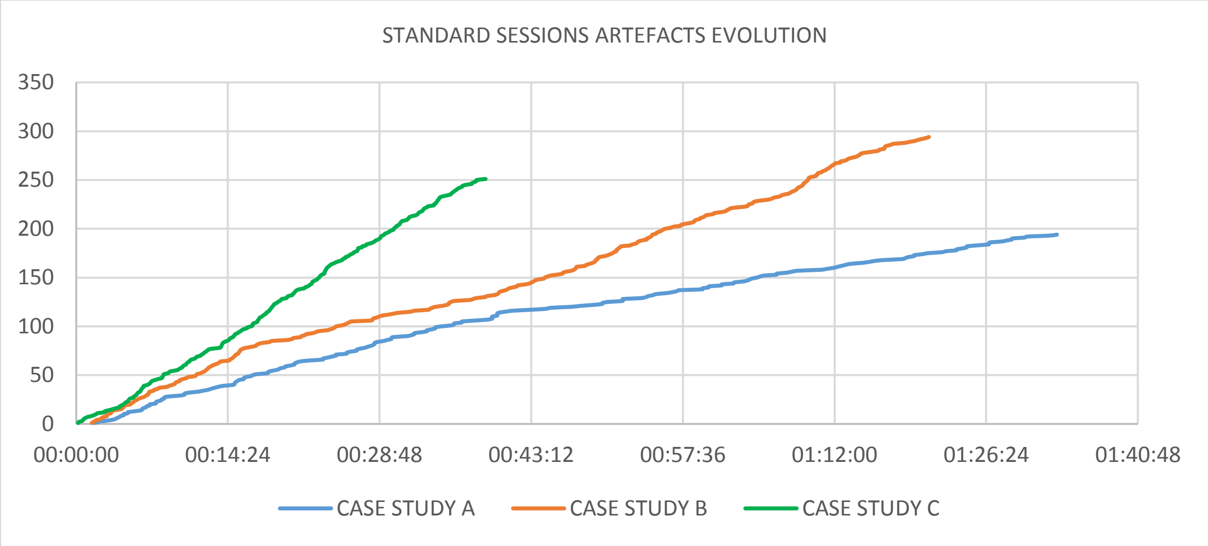


Figure 92.Overview of artefacts evolution in standard sessions

Case study A, despite being the longest session 1hour 33 minutes, shows the lower rate of artefacts' evolution. It involves less than two hundred interactions. The average of interaction for this session is 2,19 interaction per minute.

Case study B shows the highest number of interactions recorded in standard sessions. This meeting lasts 1hour 21 minutes and covers 297 interactions; which brings an average of 3,66 interaction per minute.

The last standard session was the shortest one with 39 minutes duration. Case study C run in our lab involves 249 interactions and gives 6,38 interaction per minute.

These results show that standard sessions based principally on tangible artefacts present a low rate of interactions per minute between participants. The last standard session which involves more the digital artefacts presents the highest rate of interaction evolution and an important average of interaction per minute. This result encourages us to explore collaborative design session supported by digital means.

5. Place of ephemeral artefacts in standard session

We observed that ephemeral artefacts were important media to enrich design collaboration and facilitate communication between different stakeholders during the sessions. Davis confirms the key role of gestures in design activity. He underlines that to effectively communicate their idea, the designers complement their sketch by using gestures as a communication tool (Davis, 2016).

We highlight in this paragraph the place of ephemeral artefacts in these standard sessions:

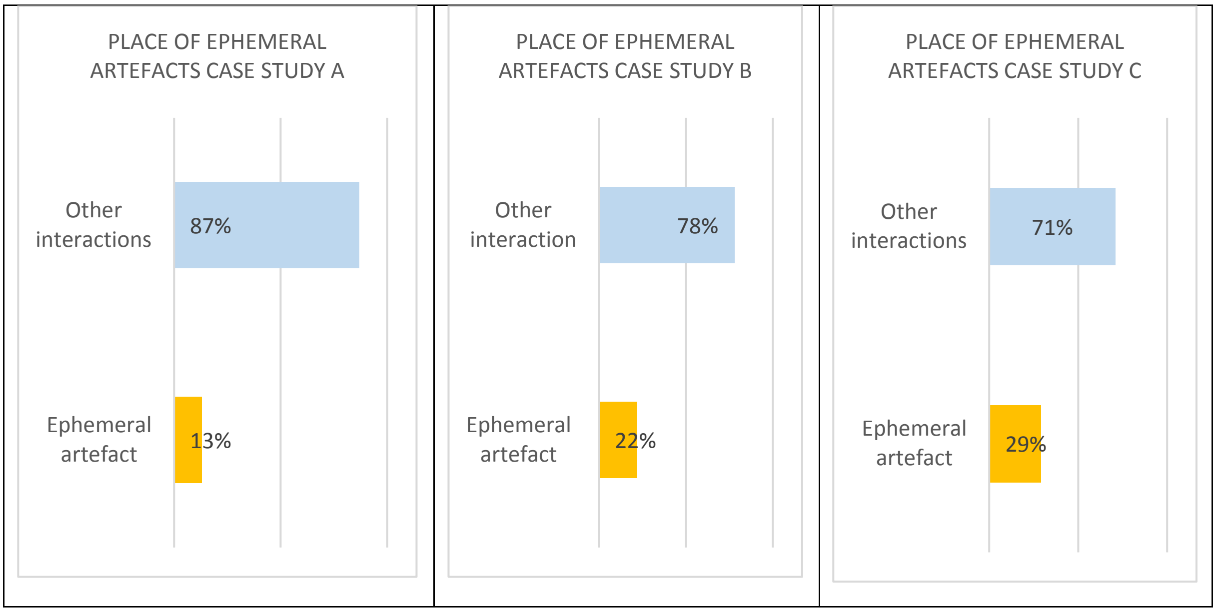


Table 16.Overview of ephemeral artefact involvement in standard sessions

The graph of table 16 shows the percentage of ephemeral artefacts on standards sessions total time. The rate of ephemeral goes from 13% to 29%, which represents a significant amount of interactions. We can consider that standard sessions have an acceptable average of communication through gestures in the air. These results will be considered later to be compared with sessions using dedicated ICT tools. We will be able to see if the collaborative design sessions supported by augmented and spatial augmented reality tools improve this rate or not.

Discussion

The presentations of the results from the three first cases studies show that standard sessions A and B are similar in term of artefacts involved, tangible artefacts are the most involved 57% for case study A and 56% of tangible artefact for case study B. The interactions modalities used are manipulation with 37% for case study A and 26% for case study B. The rate of client participation is equal for both sessions 30% of total meeting time.

However, case study C presents a different profile, the most involved artefact is the digital one with 30% of total time. The modality most used is the pointing with 40%. Additionally, end-users' participation in the design task is limited to 5% of session total time.

We spot that analysis results of case study A and B are quite similar. These two meetings were held in the design agency premises. They involve same design actors profile with almost same design equipment and environment condition.

On the other hand, and despite our intention to carefully replicate the industrial environment for the artificial situation in our lab, the results show a different session's profile for case study C. We spot the differences in all aspects, favourite artefact and interaction modalities involved but especially the implication of clients comparing to the end-users. At a first glance, we could consider that this difference is due to the design setting, but we also stressed that the participants involved were end-users and not clients, which represents another big difference. We believe that the later influences more the results that the observation setting. This has to be confirmed however by other observations.

CHAPTER II: collaborative design session with ICT tool

Abstract

The use of three-dimensional virtual elements is a key element for multiple area as architecture, scientific research, and product design. Indeed, the possibility to visualize and interact with a three-dimensional representation of 3D virtual models are of great interest in the context of their specification and design(Segers, Achten, Timmermans, & Vries, 2000).

As presented in the first part, Augmented Reality (AR) can be defined as the mix of the real world and the virtual world. Based on this concept, this Chapter focuses on the application of AR in a collaborative framework for product design. In particular, we focused on the concept of a tabletop meeting where multiple people can simultaneously manipulate 3D virtual or mixed elements in a shared space.

We suggest Augmented Reality (AR) as a first trial that allows the integration of virtual objects in our real environment. Then, we present a Spatial Augmented reality platform supporting a real product design meeting. These two technologies enable participants to handle virtual and mixed objects naturally. Based on this concept, a user may maintain his usual collaborative environment while integrating 3D interaction possibilities.

In this context, incorporating the virtual into the real world can raise a certain number of questions: "How to interact with the virtual object? And the mixed object?" and “Does mixed object enhance interactions between design meeting participants comparing to session involving standard technological tools?”

1. Augmented reality situation

A. Case study D

For this case study, we set a collaborative design session within the integration of an existing ICT tool provided by our partner in Politecnico di Milano. In this condition, we provide the participants with a relevant technology that might be considered as a way to compare it to a standard session and other sessions supported by a Spatial Augmented reality Platform.

Figure 93.Illustration of Case Study D

The ICT tool used for this session is an augmented Reality version of SPARK platform. This case study was around a sport product, which is a smart fitness product to monitor performance when using gym equipment.

1. Profile of artefacts

Case study D session gathered two designers and three potential end-users. The aim was to define the colours, materials and finish of the main housing product. Designers expect discussion about the interface look and especially the location of logo.

a. Place of artefacts in the session

Analysing this session with the first grid level brings the following findings: the importance of different types of artefacts in collaborative design session.

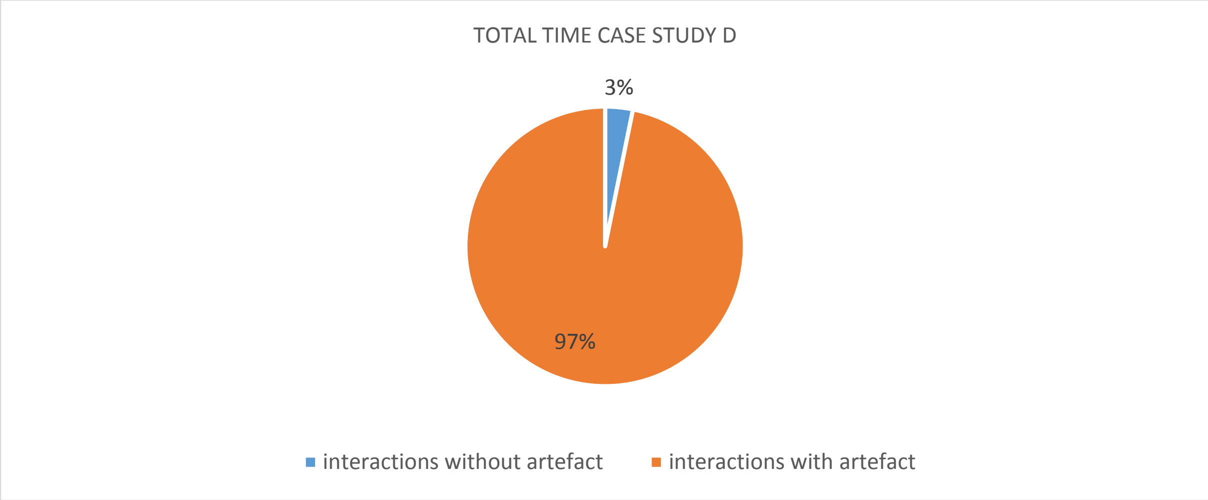


Figure 94.Total number of interactions in Case Study D

The breakdown of Figure 94 shows that artefacts hold a central place in collaborative design session. With 96% of total session time artefacts are involved in the core of the process. The exchange between participants of session is supported by the mean of artefacts. We also can assume that even with different tools and design objects, the design session still to be well supported in the majority of time by the mean of artefacts.

b. Artefacts' repartition in the session

Since the artefacts occupy an important place in this session, we study the repartition of use through the following graph:

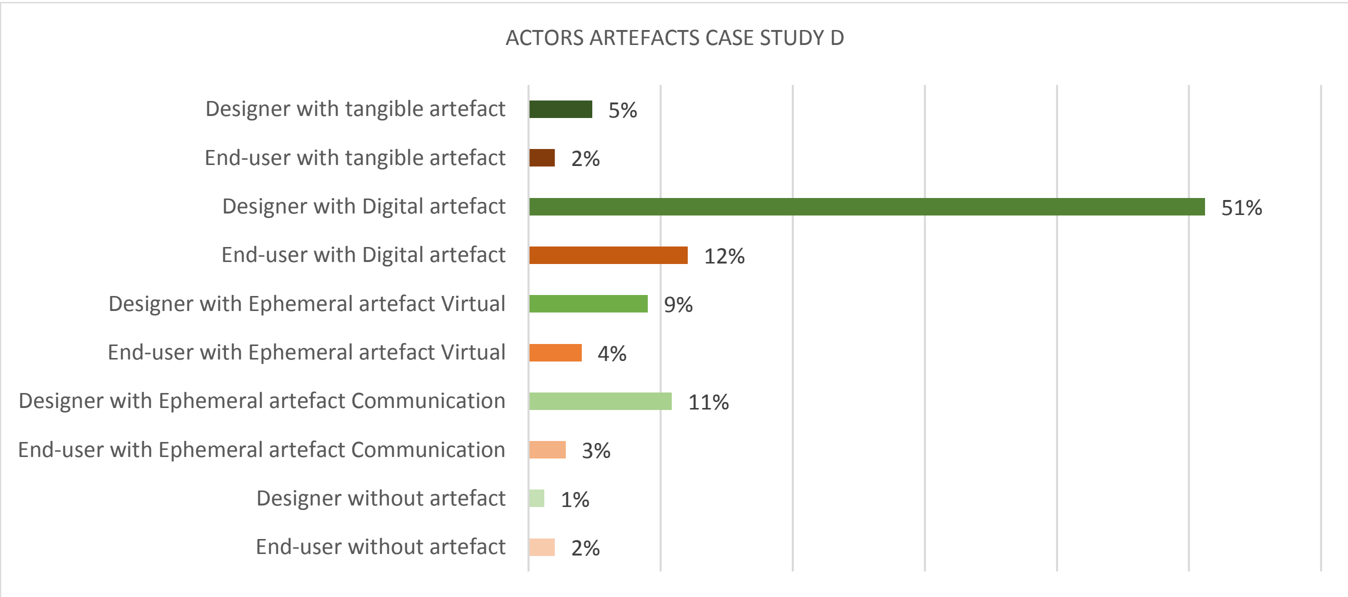


Figure 95.Distribution of artefacts used in Case Study D

Figure 95 highlights an important percentage of digital artefacts 63% used during the case study D. Both participants (51% from the designer and 12% for the end-user) prefer to interact with the digital design representations, which are the augmented reality tablet and its marker.

Simulation of shapes through gestures, and mimicking hands functionalities represents 4% from end-user and 9% from designer. The tangible representations have been only manipulated with 5% from designer and 2%from end-user. Finally, with the percentage of 14%, session's actors use gesture while talking in purpose of oral communication.

c. Evolution of artefacts during the session

The following graph draws the evolution of each artefact used during case study D:

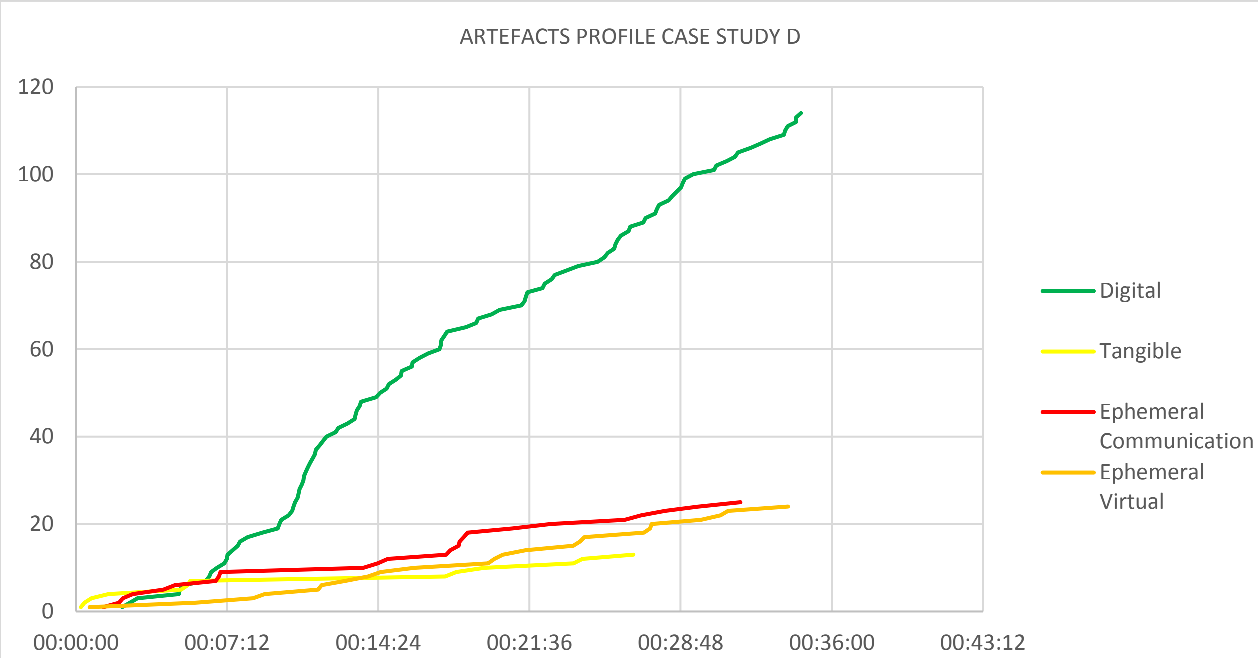


Figure 96.Evolution of artefacts in Case Study D

In accordance with the results from the diagram of actors artefacts (figure 95), the evolution of artefacts graph(figure 96) characterizes the session with an important involvement of digital design representation. A remarkable increase of digital use comparing to a limited involvement of tangible and ephemeral ones. Both of them were modestly used on the entire session with a low rate of evolution.

These results can be explained by the setting of the meeting room with a group that focuses on augmented reality tablet and the physical object. This set may incite the participants to express more their ideas using the digital design representations. Despite that, we cannot deny that tangible artefacts and the gestures in the air still represent a good amount of interactions: if participants feel the need to express their opinion with an unavailable instrument, they may sketch, draw or try to mimic it through gestures and it still a good option for them.

2. Profile of interactions modalities

a. Repartition of interactions modalities

In this paragraph, we will analyse our results with the second level of our framework, which is related to modalities of interactions. We will try to understand through which modality the participants prefer to interact:

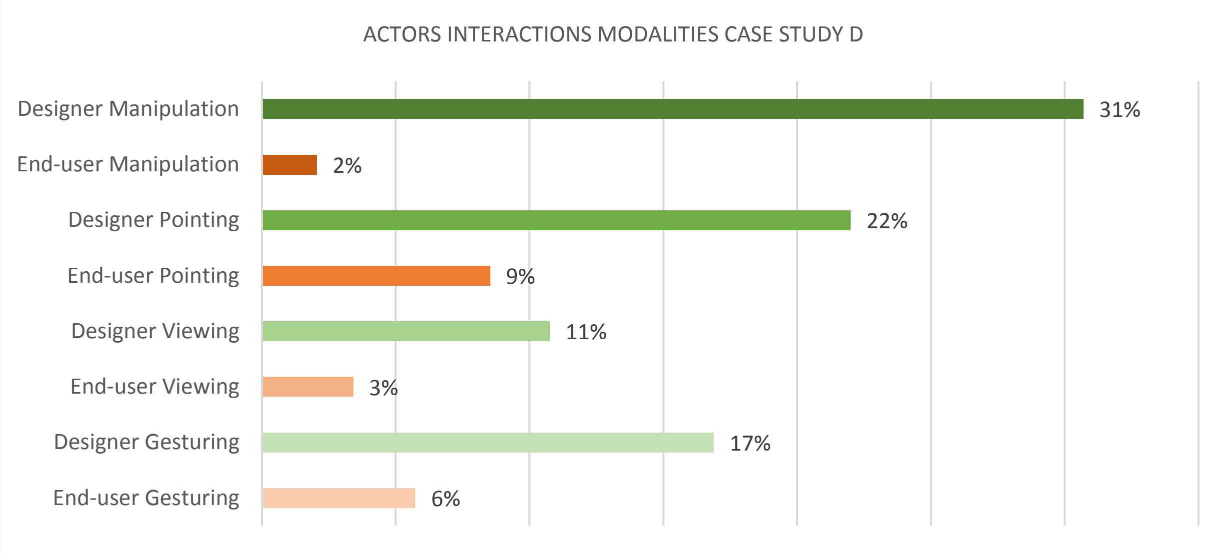


Figure 97.Distribution of interactions modalities in Case Study D

The graph shows that the manipulation of artefacts reaches about 33% which include holding, modification, annotating and sketching. This is the most common way to interact with design representation especially for designer (31%) but only 2% for end-user. The designer was in charge of the modification through the augmented reality interface, so he dominates the session. However, the end-users surprisingly manipulated the artefact at a low level while they could easily do more. The end-users interacted more with the pointing 9% modality. Designers still dominate with a pointing rate of 22%. Discussions with only gazing at the artefact is most used by designer (11%) than the client (3%). We observe also a good rate of gesturing 23%; it is involved between 6-17%. Overall, we notice a low engagement of the end-users in this session, suggesting a low level of participation, at least relatively passive end-users.

b. Evolution of interactions modalities

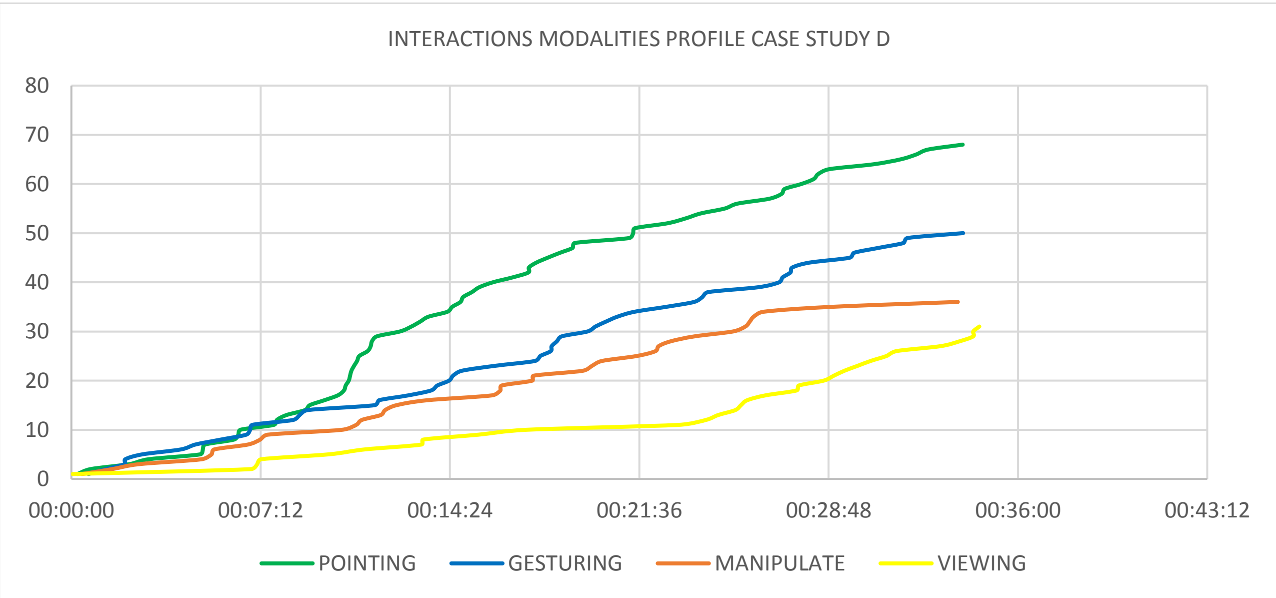
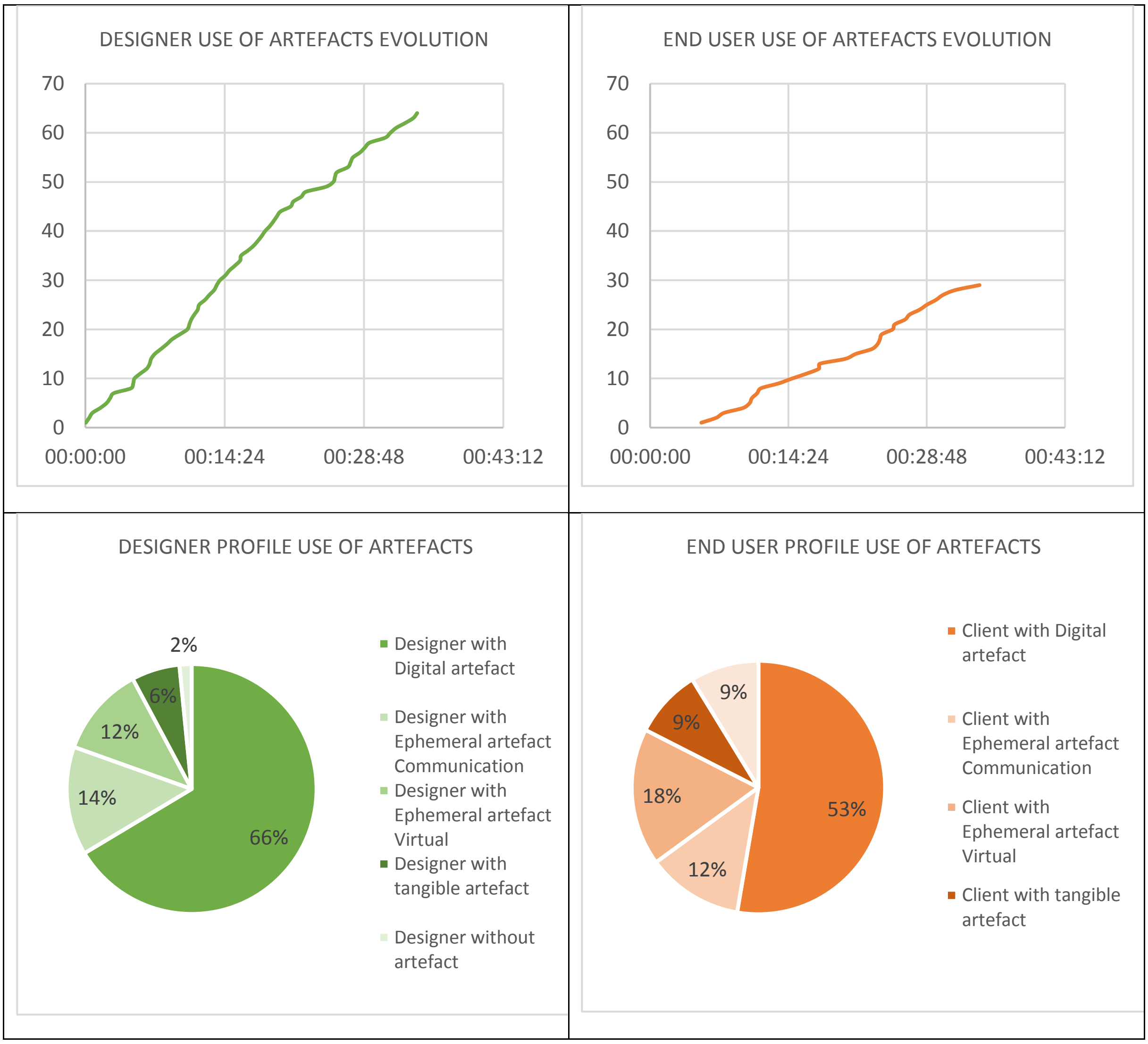


Figure 98.Evolution of interactions modalities in Case Study D

The profile of modalities used during case study D session highlighted at the beginning a collective evolution of all modalities. Gesturing was the favourite modality of interaction during the first six minutes while the designer presented the product and plan of the session. Then once the task started, the actors privilege the pointing (around 10 minutes) but still also use with a lower rate of evolution the gesturing and manipulation of artefacts. The viewing modality record the lowest rate of evolution during the case study D session for both actors. However, we can notice an inflection in the evolution rate around 25 minutes which suggests a more important engagement or a specific task at that time.

3. Profile of participants

In this section, we will draw a profile for each session's participant. In order to show who is the most active participant and through which artefact and modality he explains better his needs and opinions. Case study D session involves two designers and three end-users, on table 17 we present their profile during this meeting presenting their evolution in term of use of artefacts, then the most used artefact and the most employed modality of interaction.



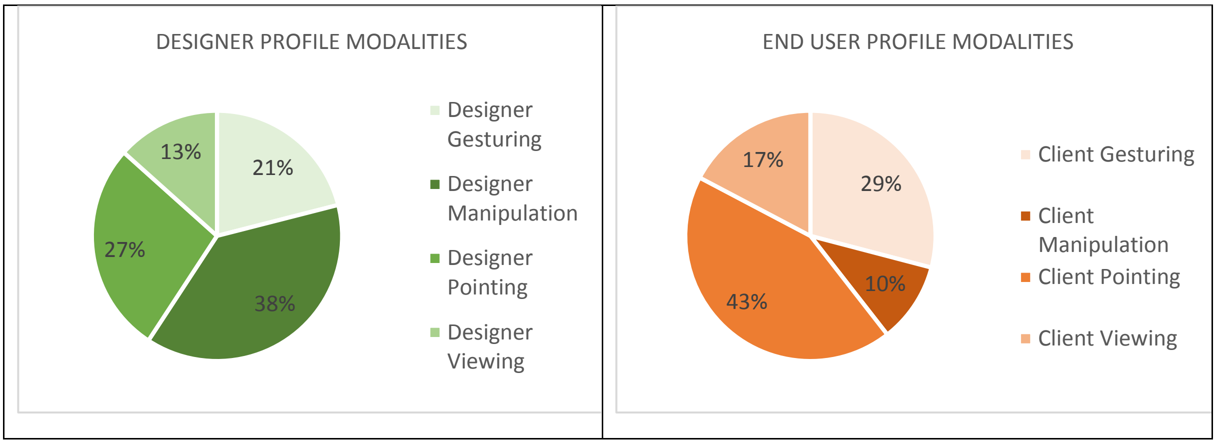


Table 17.Detailed profiles of participants in Case Study D

The profile of artefacts' evolution manifest a huge difference between the implication of designer and the end-user, which reflects their engagement during the sessions. The curve of designer's evolution in the session presents more than twice of the end user's one. This can be explained by the nature of profiles; when a co-design session run with end-users it presents a very limited contribution comparing to a session with a real client. This difference is probably also due to the fact that designer is more fluent in using the technology supporting the session than the end-users who are not necessarily familiar with augmented reality. Therefore, the designer leads and initiate the majority of interactions during the meeting.

The profile of the participants in case study D session are heterogeneous in term of use of artefacts and modalities involved. They mostly interact with digital artefacts 66% for designer and 53% for end-user, but they diverge in use of ephemeral artefacts. Designer prefer the ephemeral gestures for communication (14%) than the simulation of object (ephemeral virtual 12%). This is exactly the opposite behaviour of end-user who privilege the ephemeral virtual to express his ideas (18%), a bit less with ephemeral communication artefacts 12%. Both actors present a limited rate of interaction with tangible artefacts 6% for the designer and 9% for the client.

In term of modalities, the participants present fairly different profiles. The designer prefers manipulation with 38% of his total time, when it represents only 10% of the end-users' time. This is may be due to the lack of familiarity with augmented reality platform. In line with the previous remark, pointing was the preferred modality for the end-users with 43% and 27% for the designer. The gestures in the air are used by both participants but more involved by end-user 29% and 21% for designer. The least modality used is viewing with 17% for end-user and 13% by designer.

2. Spatial Augmented Reality situations

A. Case study E:

The case study E is a collaborative design session using Spatial Augmented Reality technology. During this meeting, participants will test the SPARK platform in a controlled environment provided by GINP lab. The platform set for this experiment was the official 'release 1' of the SPARK platform.

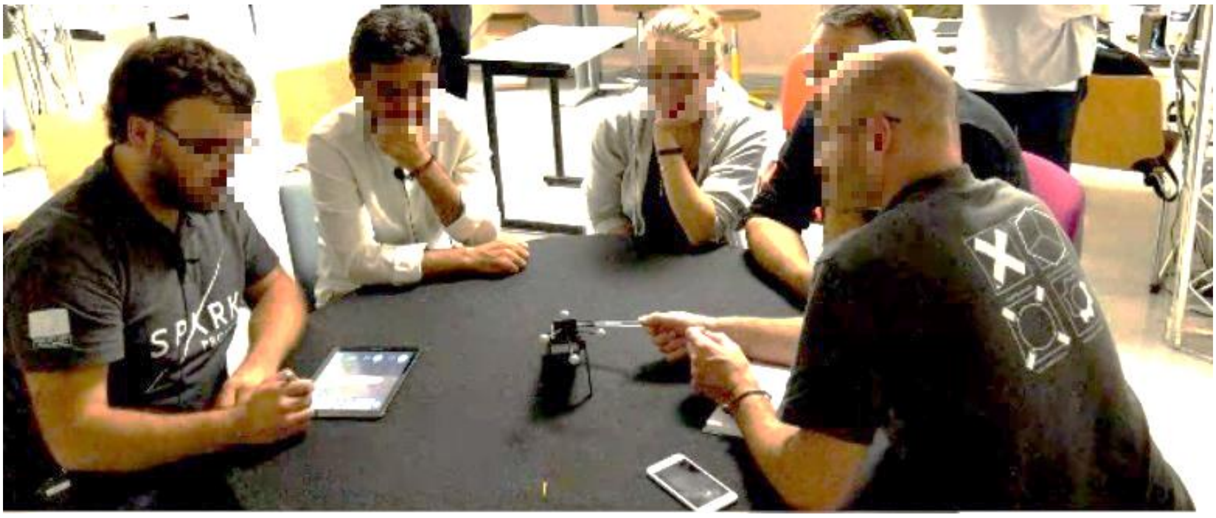


Figure 99.Illustration of Case Study E

The product tested within this case study is a hand held device for assessment of human exposure to electromagnetic fields. The aim of the meeting is to discuss with end-users about colour definition, materials and finish of the main housing. It is also about how to define the location and pattern of LED status lights and speaker and the location of the logo.

This collaborative design meeting involved two designers from the design company and three end-users recruited by Grenoble INP team from design engineering students (one graduate and one undergraduate) and on technical staff member.

1. Profile of artefacts

a. Place of artefacts in the session

In order to analyse the session, we start by quantifying the amount of interactions supported by artefacts during the meeting. As the following breakdown shows, different artefacts support most of the session interactions 92%.

Again, we can check the hypothesis that with a different technology and in different working conditions (here in controlled lab situation), artefacts still play a major role as a medium of exchange between collaborative design actors.

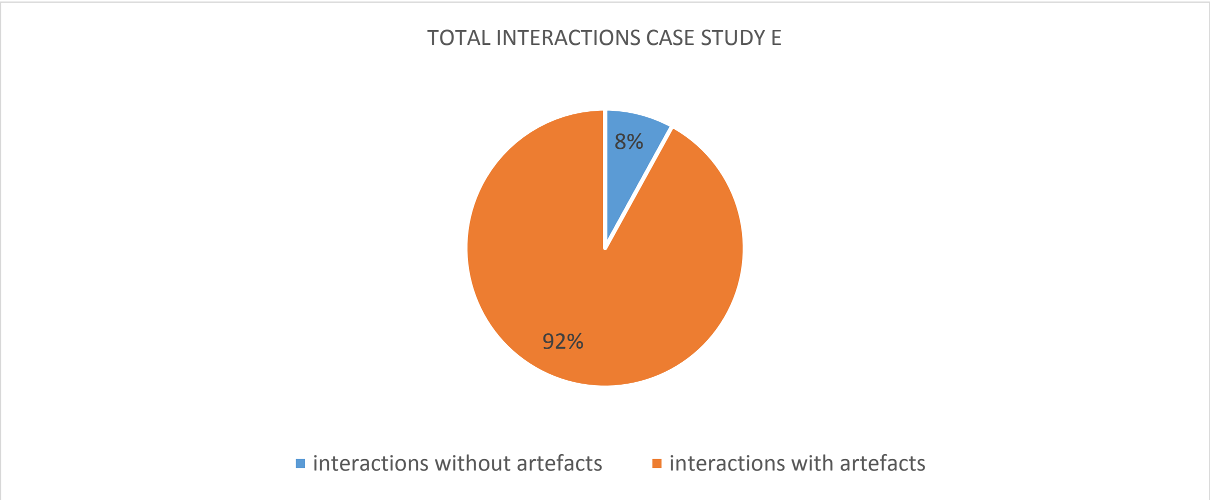


Figure 100.Total number of interactions in Case Study E

b. *Artefacts' repartition in the session*

Considering the importance of artefacts in collaborative design meeting, we will give a special focus on their repartition of use by different participants in a session using a Spatial Augmented Reality platform:

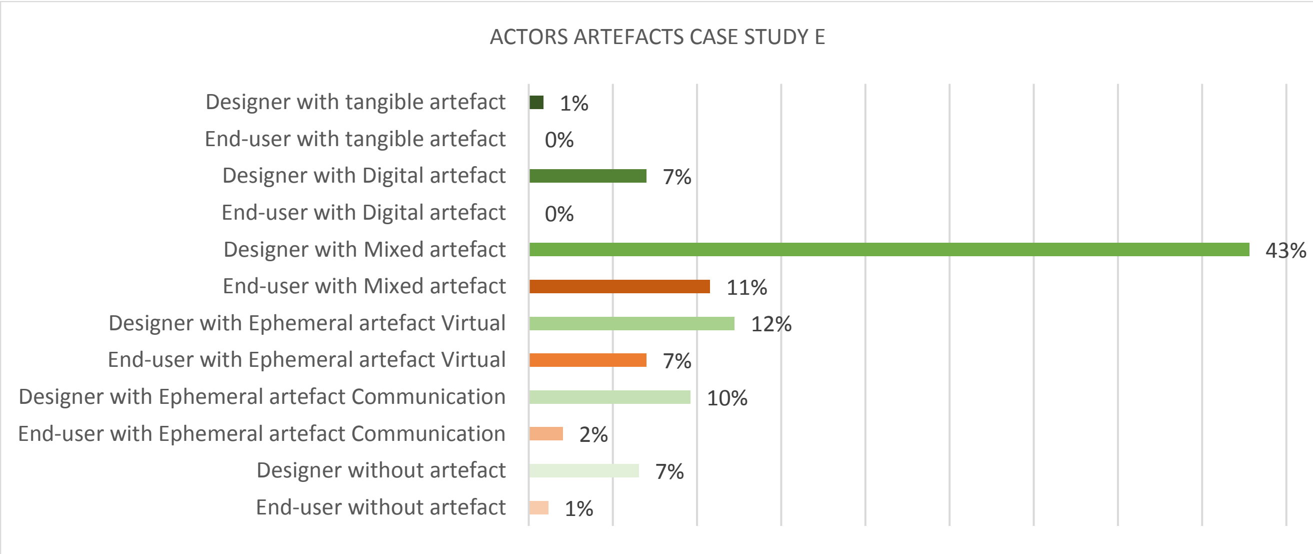


Figure 101.Distribution of artefacts used in Case Study E

The session is characterized by an important use of mixed artefacts 54%, the Designers with 43% of the session time and the end-user with 11% respectively. The ephemeral virtual artefact category is the second preferred interaction media 19%; 12% for designer and 7% for end-user. Tangible and digital representation present a very limited involvement only by designer 1% and 7%. End-user do not feel the need to use them at all. We observe that the SAR platform with its mixed object satisfy the participants, and they focus their discussion around this tool. Ephemeral gestures are still present in the SAR session.

c. *Evolution of artefacts during the session*

The following graph presents the profile of different artefacts during the course of the session:

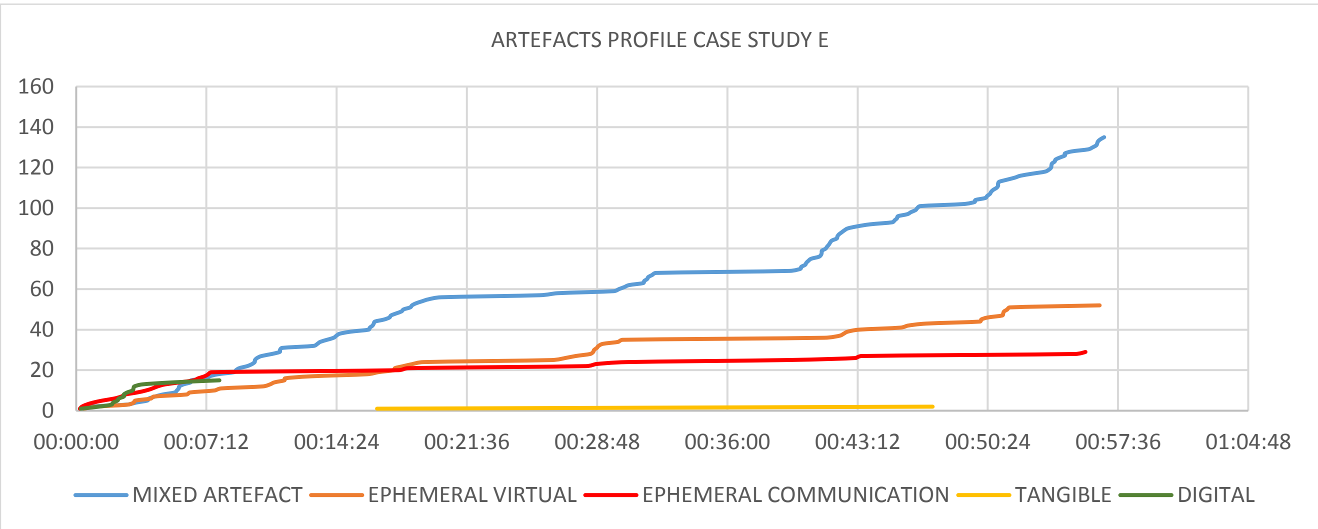


Figure 102.Evolution of artefacts in Case Study E

The first seven minutes of session, that are generally dedicated to a global presentation of the plan and aim of discussion. They are characterized by a diverse use of artefacts but mostly the digital ones.

After introducing the meeting, participants stop using digital representations completely. The group focus on mixed artefact as main representation until the end of session. The blue curve (displaying mixed artefacts) presents two phases of stagnation: from minutes 21 to 28 and from minutes 32 to minutes 40. These two phases were SPARK platform crash. For this meeting, design team was dealing with a first release of SPARK platform.

The session's profile presents a limited evolution of ephemeral artefacts and a very low rate of tangible representations. From the beginning of the meeting and until the 28th minutes, the graph shows a complementarity use of ephemeral virtual artefacts and ephemeral communication. When the rate of virtual artefact is high, the use of the communication ones decrease. The rest of the session, design team continue to involve virtual artefacts progressively. However, the ephemeral communication gestures will keep being stable until the end of the meeting.

2. Profile of interactions modalities

a. Repartition of interactions modalities

In this section, we focus on modalities of interactions used during case study E session.

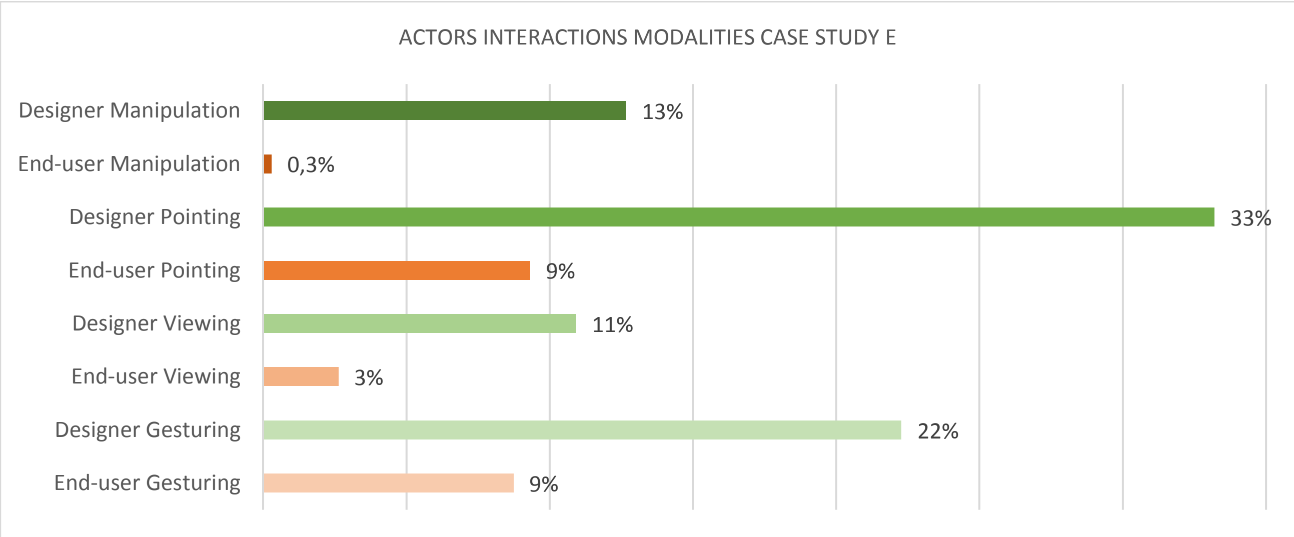


Figure 103.Distribution of interactions modalities in Case Study E

The actors' interaction modalities graph (figure 103) confirms that the designer is the main actor of session. He mainly uses the pointing modality to explicit his ideas with 33% of session total time. Pointing is also the favourite modality for the end-user associated to the gesturing with 9%. Gesturing is the second modality used by the designer with 22%. Both actors present similar choices for the modalities used: pointing first then gesturing. We may explain this preference by the meeting set-up, which places the mixed artefact at the centre of the table. Having a shared representation in the middle of table may favour the pointing modality; each time participants want to share an idea around mixed prototype they point at or gesture around it. According to this explanation, we can understand why manipulation by the end-user is very limited 0.3%, he only points when he wants to refer to mixed prototype. On the other hand, the designer manifest good rate of manipulation 13%, since he is the one dealing with the SAR tablet interface and in charge of applying modifications and suggestions during the session.

b. Evolution of interaction modalities during the session

The evolution during the case study E session of these modalities is presented by the following graph:

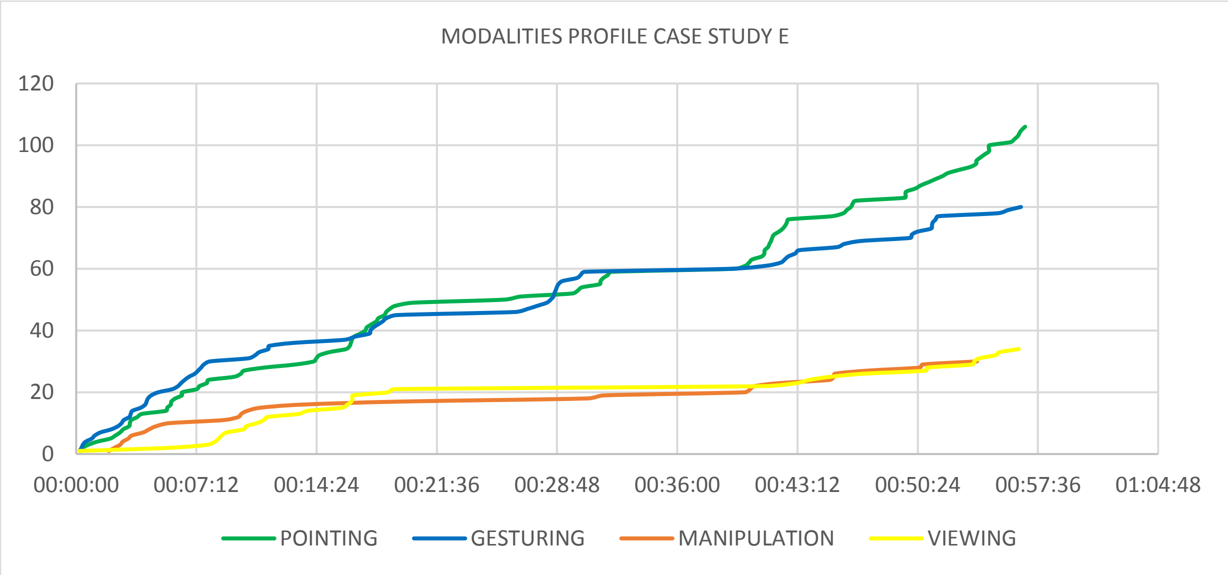
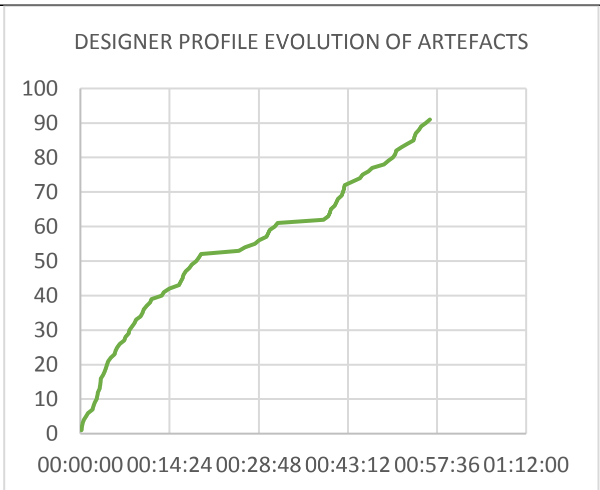


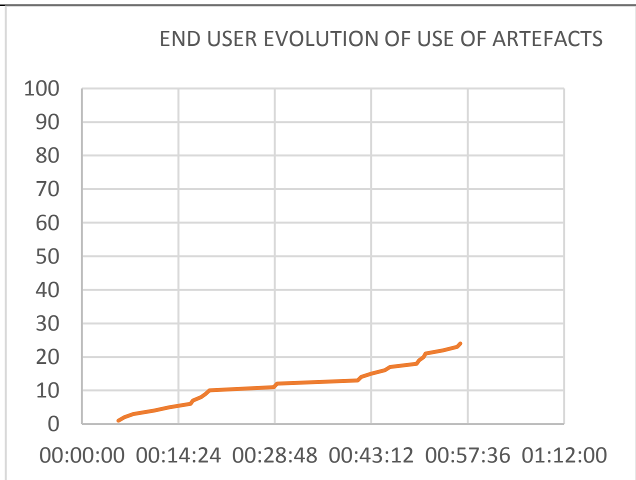
Figure 104.Evolution of interactions modalities in Case Study E

The profile of modalities presents a global dominance of pointing and gesturing comparing to a limited evolution of manipulation and viewing. This session has four phases regarding the pointing and gesturing modalities: the first fifteen minutes reflect an important evolution of gesturing comparing to pointing. This phase was about discussion when the designer is manipulating the interface to prepare a first proposal based on previous exchanges. Once the proposal is ready, the discussion turned to be supported by pointing and viewing at the mixed prototype. The third phase was based more on gesturing while the platform was facing a technical issue. The participants then continued the discussion with gestures as no visualization was available. Once the technical problem has been fixed, the participants came back to their previous interaction modalities until the end of the meeting.

3. Profile of participants

This section is dedicated to trace a profile for each actor category participating in the session. This profile gives a detailed description of each actor's involvement. Case study E involved two designers and three end-users. Below we draw their profile, presenting the evolution in terms of use of artefacts, then the most used artefact and the most employed modality of interaction:





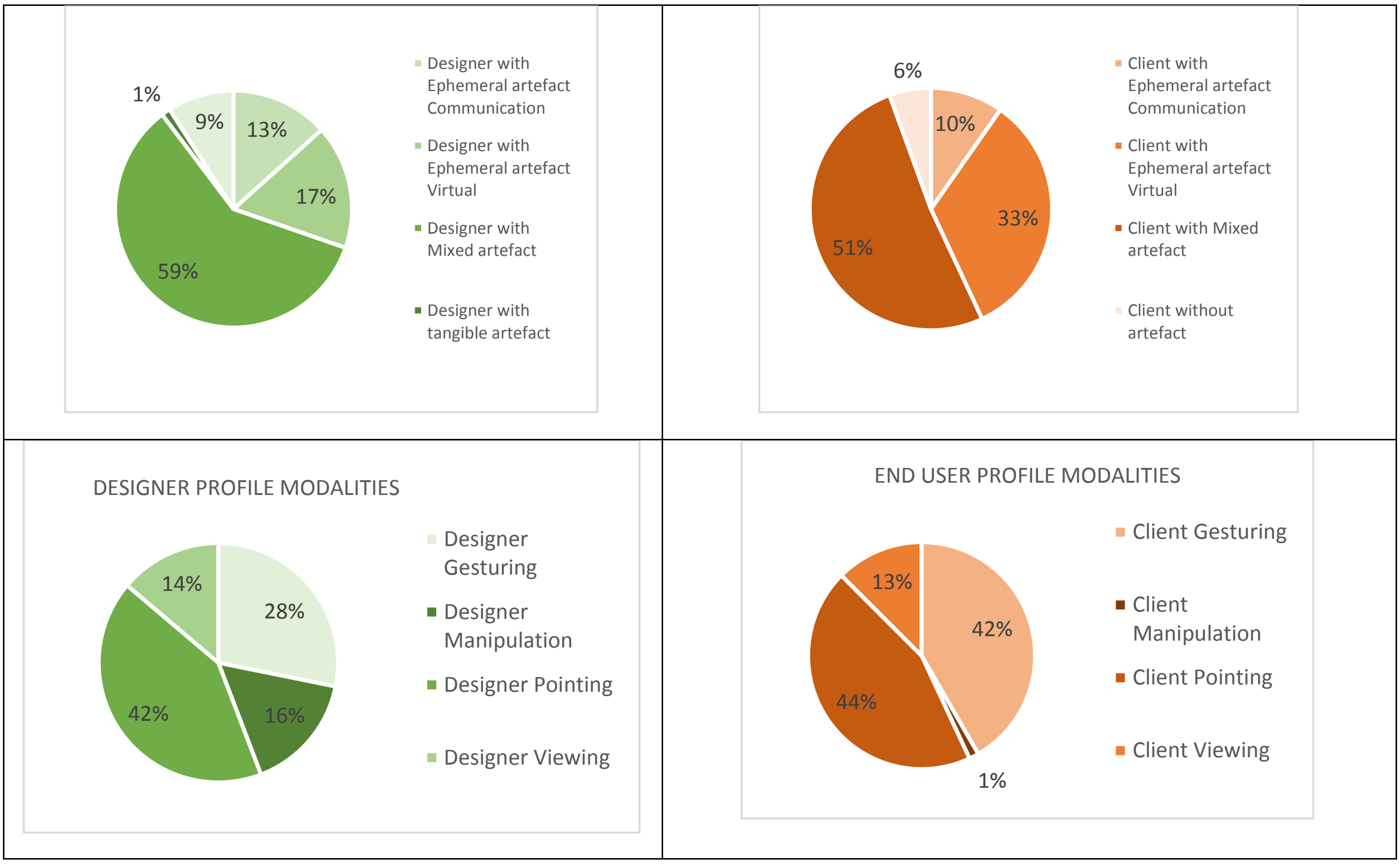


Table 18.Detailed profiles of participants in Case Study E

The profile of artefacts' evolution spotted an important difference between the implication of designer and the end-user. The designer proportion of artefacts evolution is three times more than those of the end-user. Again this result can be explained by the nature of the profiles; sessions involving end users present a limited contribution comparing to those involving real client of design agency. This difference is probably also due to the fact that the designer is more fluent in using the technology than the end-user who is not familiar with augmented reality. Therefore, the designer leads and initiate the majority of interactions during the meeting.

The profile of actors in case study E are similar in terms of repartition of most used artefact. Both designer and end-user prefer to involve mixed artefact 59% and 51% of their total time. Then ephemeral virtual artefact with 17% for designer and 33% for end-user. The designer's profile involves more types of artefacts than the end-users. Designer use tangible and digital artefacts but with a limited rate 1%. In presence of mixed artefact, end-users do not need to express their ideas through other means.

In term of modalities, the participants share the same preferred modalities: pointing 42% for designer and 44% for end-users. Gesturing 28% for designer and 42% for the end-user. A very close rate of viewing is recorded 13% for end-user and 14% for designer. Then the profiles diverge in term of use of manipulation 16% for designer and only 1% for the end-user. The latter present a very low rate of manipulation; this can be explained by the fact that only the designer manipulated the interface of SAR application.

B. Case study F

This section is dedicated to the testing of the last version of the SPARK platform at the partners' premises. We will study and analyse how and to what extent the SAR technology can stimulate and enhance design interactions through a further discussion relative to situations in real operational design environments.

The product of this session is the first non-invasive screening device for infant meningitis. The device employs a sophisticated precision-engineering system, using high-frequency ultrasound to non-invasively count white blood cell in the cerebrospinal fluid below the infant fontanel (the region of the head where the bones are not yet closed).

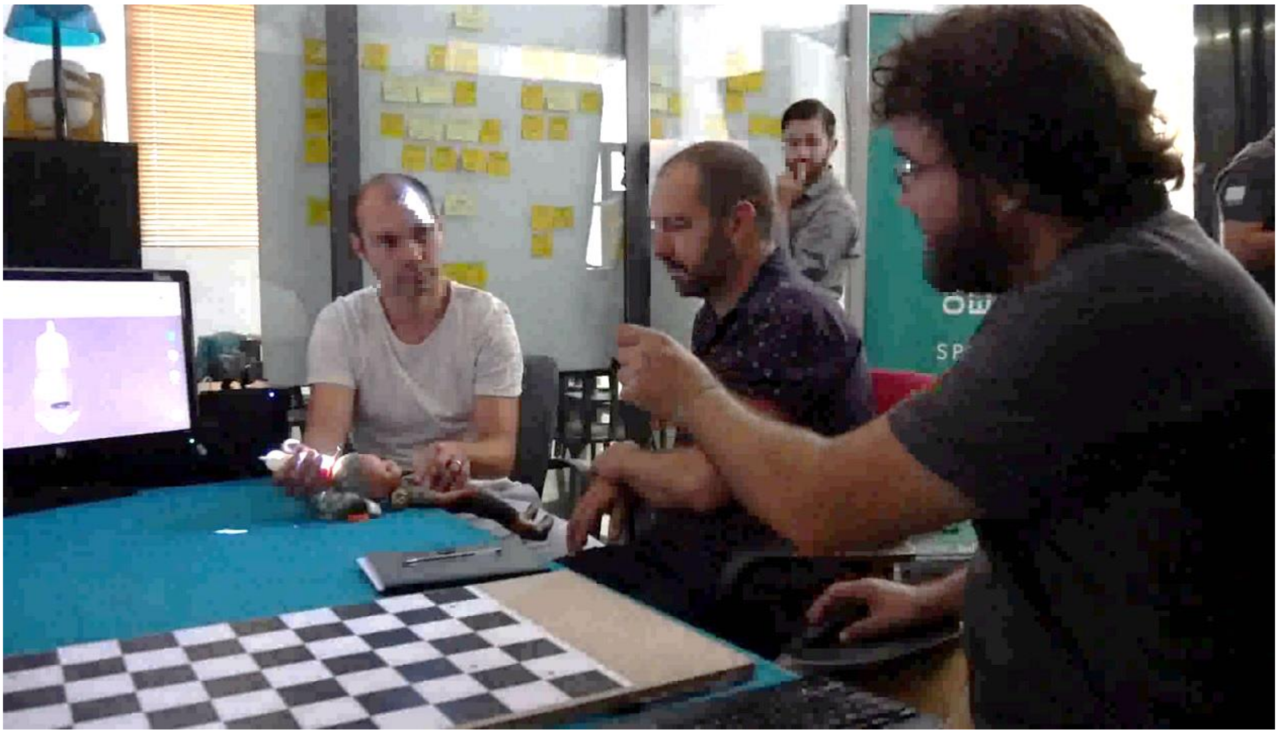


Figure 105.Illustration of Case Study F

The designers aim through this collaborative design session to define, together with the client, the best proposal to be developed. The plan is to discuss the combination of all the graphical elements prepared for the creative proposals, in order to develop potential future versions of the product and discuss the coming next steps. The main goal of this session was to shorten the number of iterations needed for the project through co-design and the potential of the spatial augmented reality, which offers the possibility to display several proposals in real time.

1. Profile of artefacts

a. Place of artefacts in the session

The analysis of this session brings some evidences; we can spot the importance of different types of artefacts involved by all participants in design session.

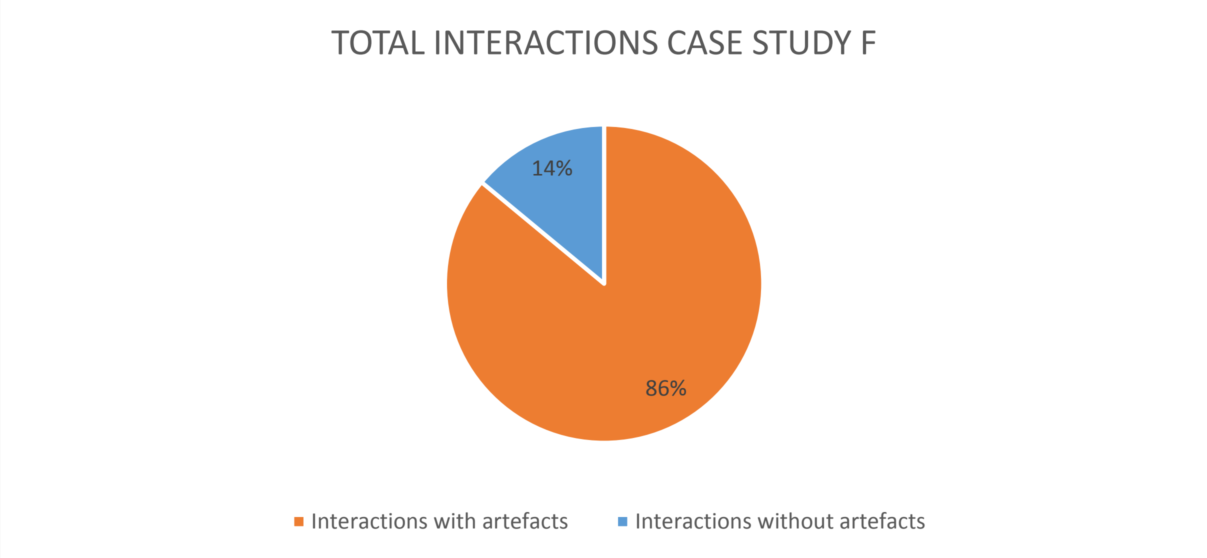


Figure 106. Total number of interactions in Case Study F

Artefacts support a very important percentage, 86% of the total time of session. Only 14% of discussion time is set without any reference to artefacts. Even in real operational environment, artefacts still play a crucial role in supporting interactions between co-design actors.

b. Artefacts' repartition in the session:

In the following paragraph we will investigate more in details which types of artefacts are involved more during case study F session and who is the actor using it.

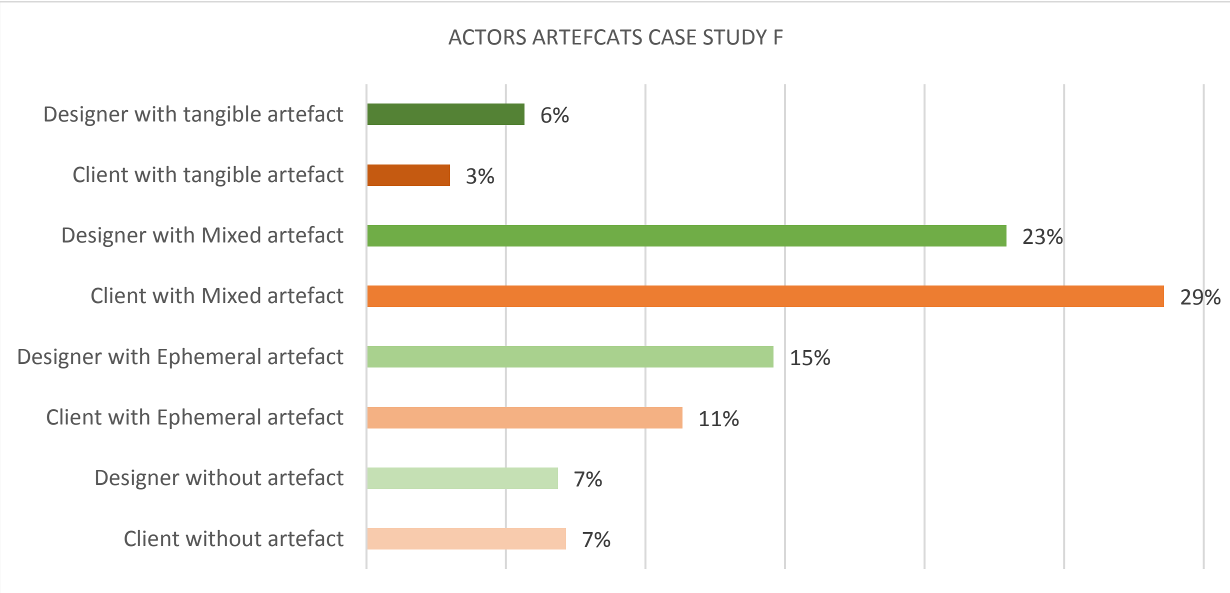


Figure 107.Distribution of artefacts used in Case Study F

The graph 107 highlights an important percentage of mixed artefact used during the case study F session. Mixed artefact is the main design representation involved during this meeting 52% of session total time. In this case study, the client seems to be more active than other sessions and even more implicated than the designer. The client uses 29% of the session total time the SAR mixed prototype. The designer also contributes more using the mixed SAR prototype with 23%. Simulation of shapes through gestures, and mimicking hands functionalities represents 26% distributed: 11% from client and 15% from designer. The tangible representations have been only manipulated 9% during the meeting; 6% for the designer and 3% for the client.

c. *Evolution of artefacts during the session*

The next graph draws the evolution of each artefact during case study F session:

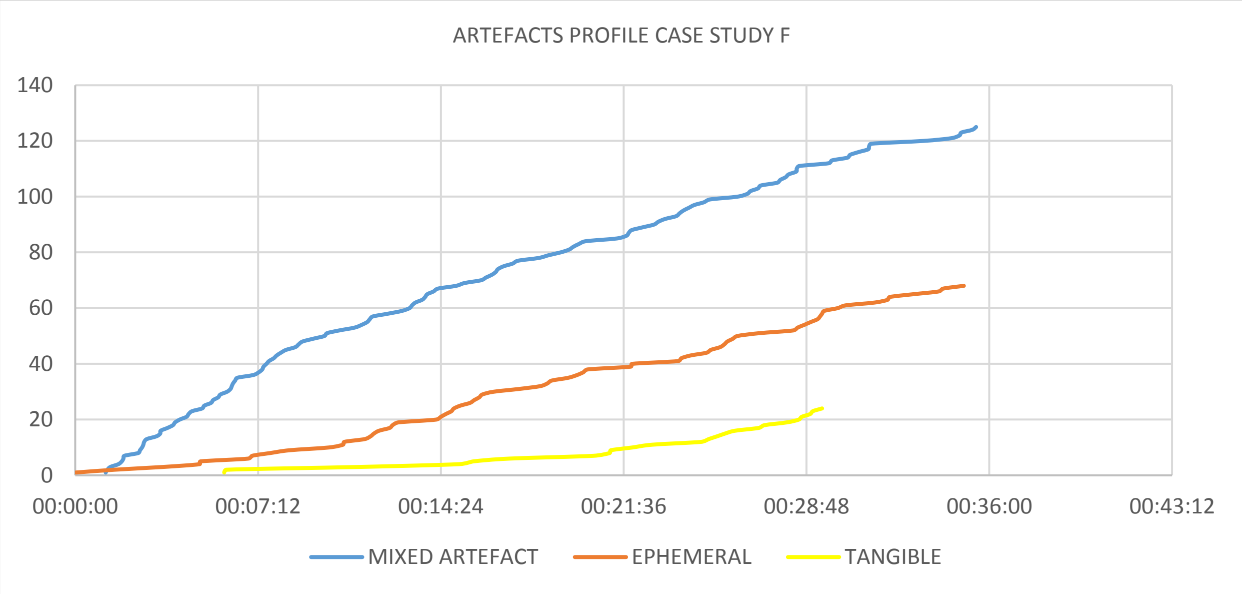


Figure 108.Evolution of artefacts in Case Study F

The difference of evolution between mixed artefacts and the rest of artefacts is quite remarkable. The session is characterised by a predominance of mixed prototypes, a very low and time limited use for tangible artefacts. Participants bring a tangible artefact (a doll) to play the role of a baby in addition to the mixed prototype. They only need it for a while during the session in order to simulate the use of the product at a certain point of the meeting. This can explain why the tangible artefact is not used until the end. Then we can spot a medium evolution profile of ephemeral artefacts[3]. Participants were dealing principally with the mixed prototype presented as suggestions of a potential final device. We notice that despite the predominance of the mixed artefact there is a significant use of gestures in the air. Unfortunately, we could not differentiate between communication and virtual artefacts, however it is noticeable that we do not see any reduction of the gestures in the air which remain approximately at the same level.

2. Profile of interaction modalities

a. *Repartition of interaction modalities*

In the following paragraph, we will analyse our results with the second level of our grid, which is analysing the interactions from the modalities point of view. We will try to understand through which modality the participants prefer to interact. The analysis brings the following results:

[3] For Case study F, the session was conducted in the design agency premises and in Catalan. Since we did not have access to the content of their speech, we cannot differentiate between ephemeral gestures for communication and gestures to simulate virtual artefacts. Therefore, the category ephemeral gestures will gather both communication gestures and virtual artefacts.

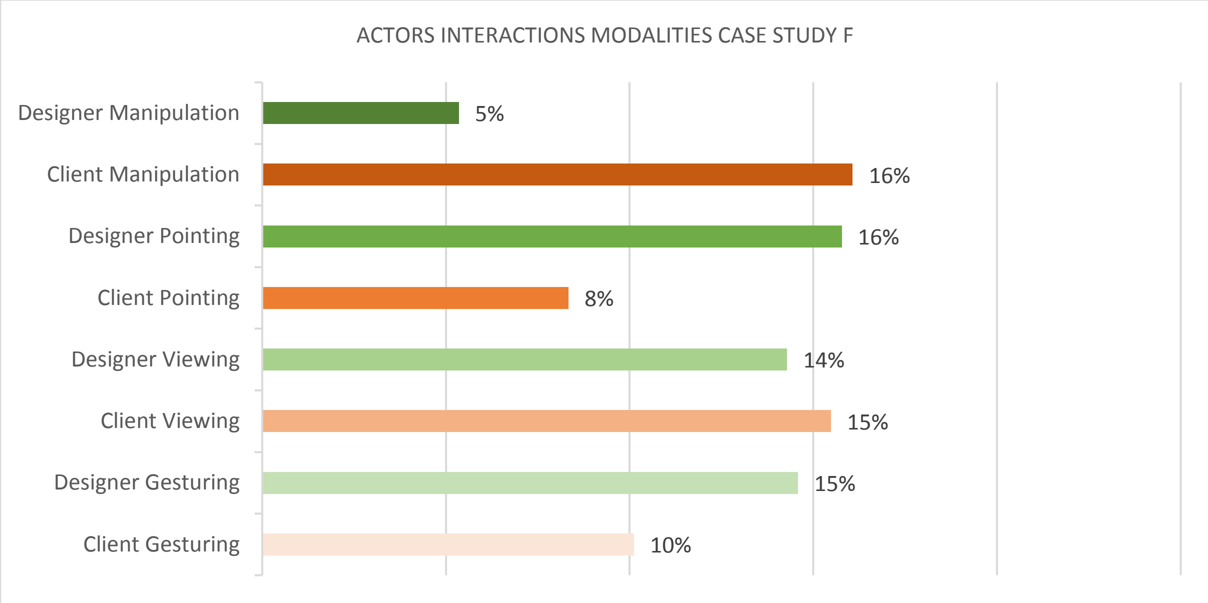


Figure 109.Distribution of interactions modalities in Case Study F

For the final case study, viewing is the most employed interaction modality with 29% of the total session time: 14% for the designer and 15% for the client. Since the session is based on SAR mixed prototype, viewing the modifications on real time is apparently the privileged way to interact between participants.

Gesturing is the second modality with 25% of the session time: The designer gestures (15%) more than the client does (10%). With approximately the same rate 24%, participants use the pointing modality. The designer points twice more than the client does (8%). The less involved modality in this session is manipulation: the client manipulates three times more than the designer does (only 5%). The latter manipulate only the interface of SAR to implement the modification suggested during the discussion. It is noticeable that the client was practically holding the mixed prototype during the totality of the session. This explains the discrepancy in the results. The designer points when the client holds the artefact and the client manipulates the artefact and the designer manipulates the SAR interface.

b. Evolution of interaction modalities during the session

Hereafter, we present the evolution of these modalities during case study F session:

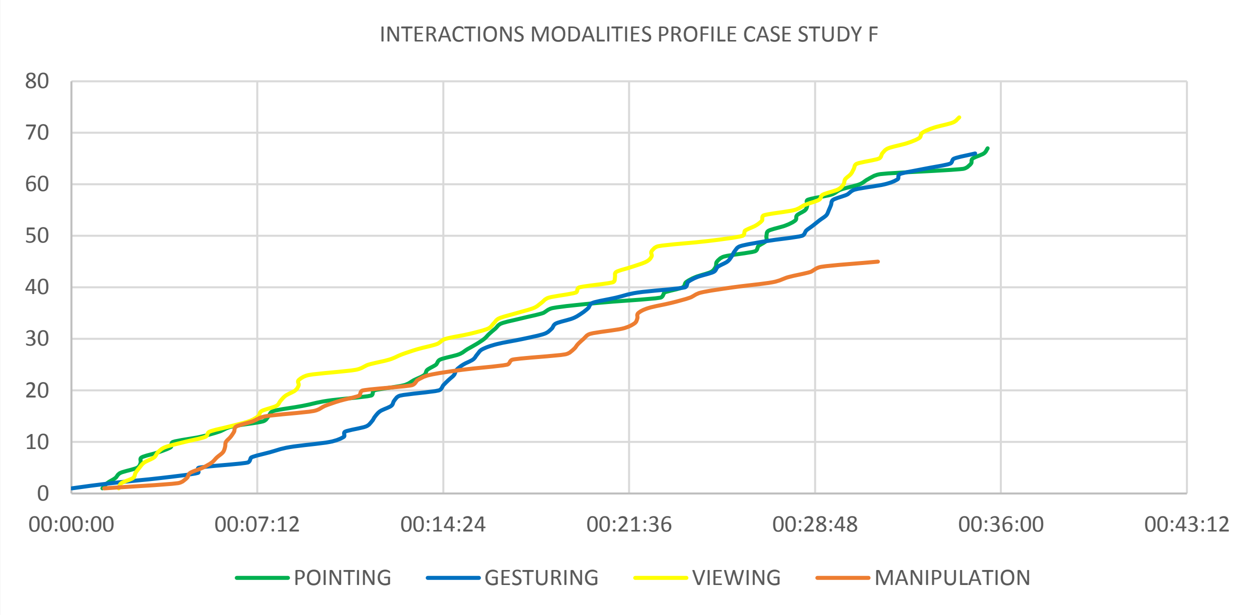


Figure 110.Evolution of interactions modalities in Case Study F

The curves of modalities' evolution during the session are quite similar. The higher rate of evolution is the viewing modality one. An important rate of pointing is recorded. The manipulation and gesturing curves present a complementarity shape. The participants seem to switch between manipulation and gestures all along the meeting. Figure 110 shows a non-monotonic evolution of the manipulation curve. We can see moments of acceleration towards the 6^{th} minutes and until 20 minutes. This actually presents the core of the meeting: designer manipulate the SAR interface according to their discussion with the client. The latter manipulates the mixed artefact with a tangible doll to observe the proposals in real time. After this phase, the involvement of manipulation will be limited and even stopped before the end of the meeting. Once the proposal is established, the discussion after is carried out by other interactions modalities. In other words, we see that when the manipulation rate stagnates, the gesture rate increases to join pointing and viewing.

3. Combination of interaction modalities and artefacts

In this paragraph, we will draw a global overview of the session with both level of grid: We will try to understand which actor uses which kind of artefact and through which modality during the entire session time:

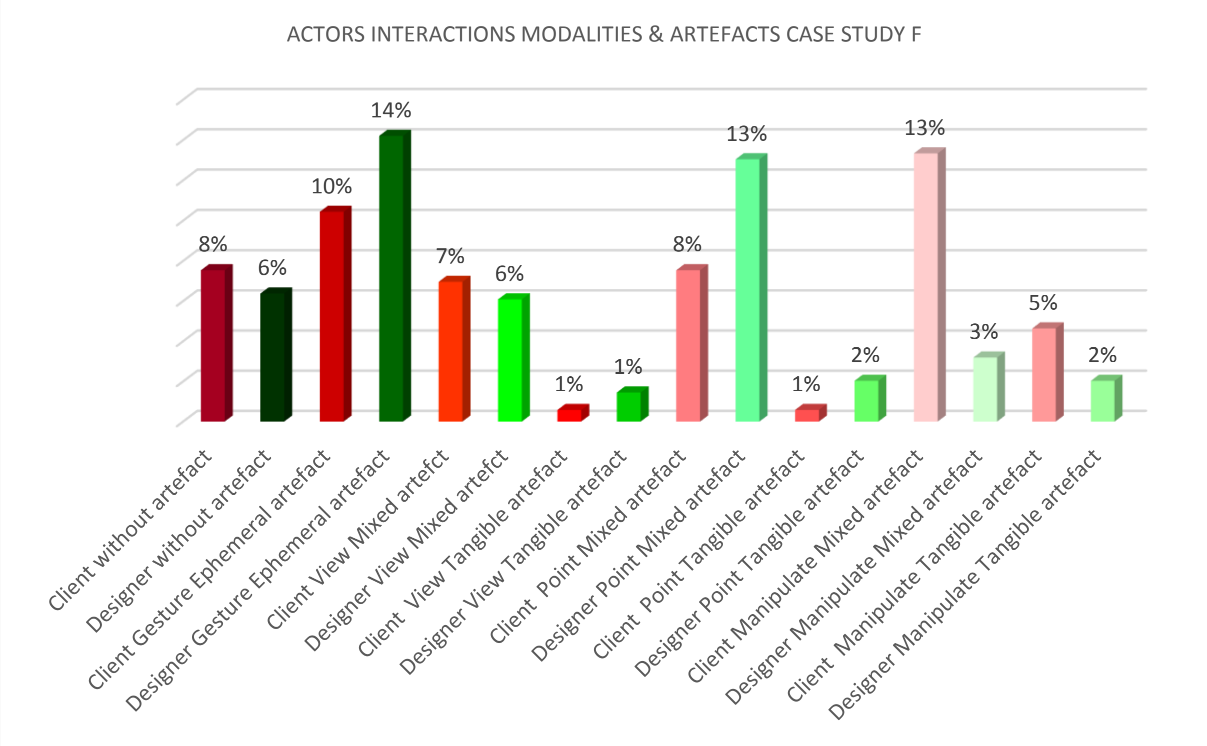


Figure 111.Combination of interaction modalities and artefacts

The combination of the two levels of coding presented figure 111 is detailing through which modality the participants interact with which artefact. The most privileged artefact used is the mixed prototype one associated to the modality of manipulation for the client and to the pointing one for the designer. This is consistent with what we said before. Discussion around the mixed artefact with only gazing is still a significant percentage (7% for client and 6% for designer). The mixed artefact helps the implication of the client especially through an important rate of manipulation 13%. We can explain this because the client was holding the mixed artefact most of the time to see concretely and comment his suggestions implemented in real-time. The designer prefers to interact with his client with exactly the same rate 13% of pointing at the mixed artefact. Therefore, the most used artefact in the session was used through an exchange of manipulation from the client's side that generates interaction through pointing on the designer's side.

The focus on mixed artefact engenders a remarkable limited use of tangible artefact. This limited use of tangible is spotted for different type of interaction modalities: viewing tangible artefact is only 1%, pointing tangible artefact is up to 2% and manipulating is up to 5%. These percentages remain a restricted use of the tangible artefacts in session supported by the spatial augmented reality tool.

During this collaborative design session based on SAR platform, the gestures in the air are an important way of interaction between participants 14% from the designer's side and 10% from client's one.

4. Profile of participants

In this section, we will draw a profile for each actor. In order to understand who is the most involved actor and the repartition of each participant time. Case study F involved two designers and one client below we draw their profile during this meeting presenting their evolution in term of use of artefacts, then the most used artefact and the most employed modality of interaction.

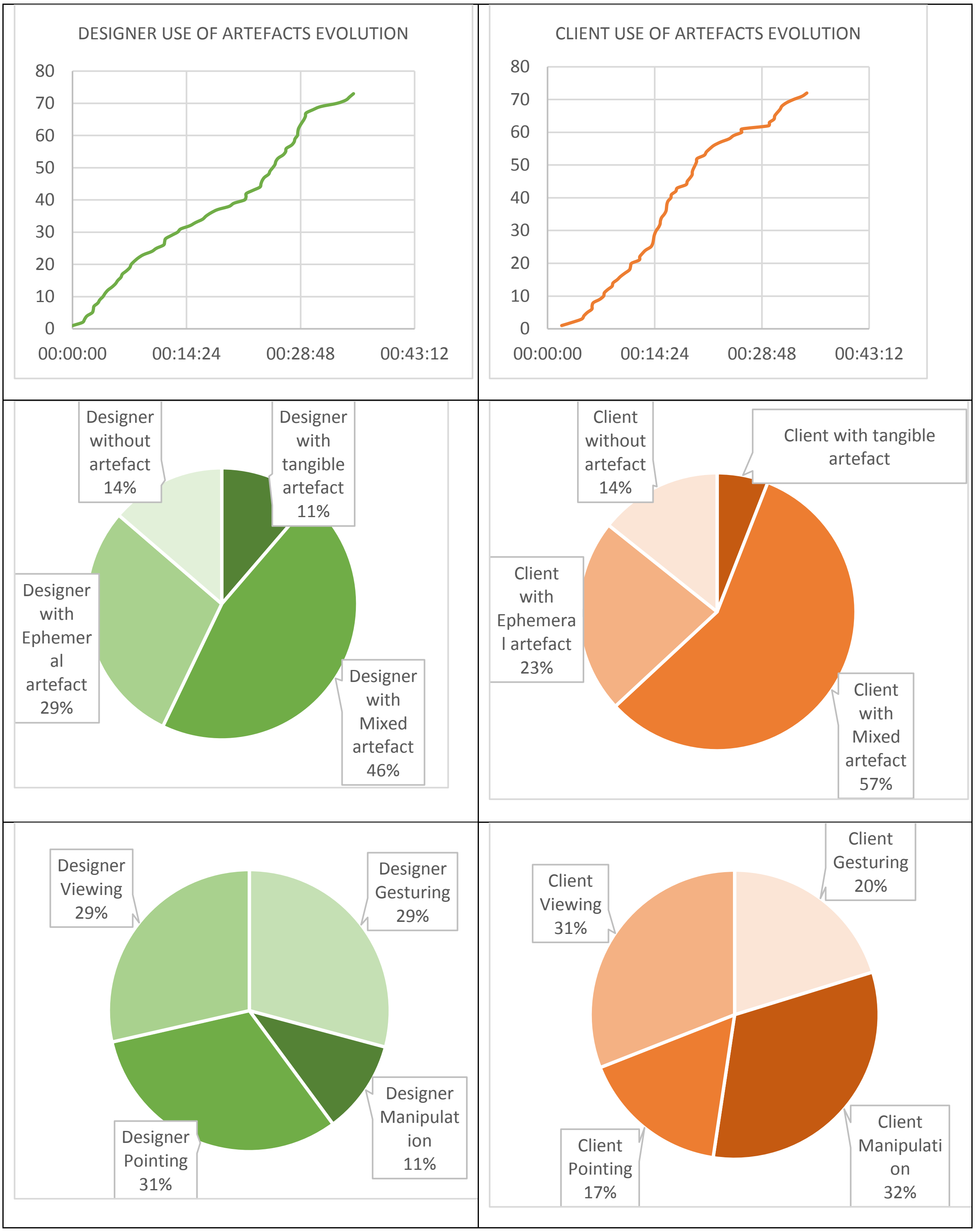


Table 19.Detailed profiles of participants in Case Study F

The use of artefact for both participants draw a very similar line. This confirms that the involvement of different design actors was equal. This session supported by the mean of Spatial Augmented reality, helps the client to be more implicated than other sessions and so having the same rate of artefact involvement.

The repartition of use of these artefacts is approximately the same for the designer and the client. Both of them interact more with the SAR mixed prototype: 46% for designer and bit more for client 57%. Then, again, both of them keep the same second privileged artefact and they interact with a similar proportion of ephemeral gestures: 29% for client and 23% for client. Finally, the limited rate of interactions with tangible artefacts is distributed to 11% for designer and only 6% for clients. In presence of SAR prototype, the use of tangible is limited to some notes on the designer's notebook or to the manipulation of a doll to simulate a baby.

The repartition of modalities is different from one actor to another. Client prefers to interact through manipulation as he was holding the mixed prototype all over the session. He spent 31% of his total time gazing at the prototype, 20% gesturing and 17% pointing. However, the designer prefers to interact more with pointing 31% and spent 29% of his time gesturing and viewing prototype. Manipulation was limited to 11% only for the SAR interface. This last case study session supported by SAR mixed prototype, shows that the client is encouraged to manipulate the principal artefact of the session more than the designer does.

3. Analysis and discussion of sessions supported by ICT tools

1. First hypothesis

We investigate the role artefacts play in collaborative design session supported by ICT tool. As reported by (Vyas et al., 2013) Design artefacts play a pivotal role in supporting communication and coordination between co-designers. We assume that artefacts are important tool of collaborative design discussion and they support the interactions between participants. We present the hypothesis:

H1: Investigating the time design practitioners spent using artefacts during a collaborative design session demonstrates the important role the artefacts play in a collaborative design session. We can consider the artefacts as an interaction communication channel same as verbal or gestures.

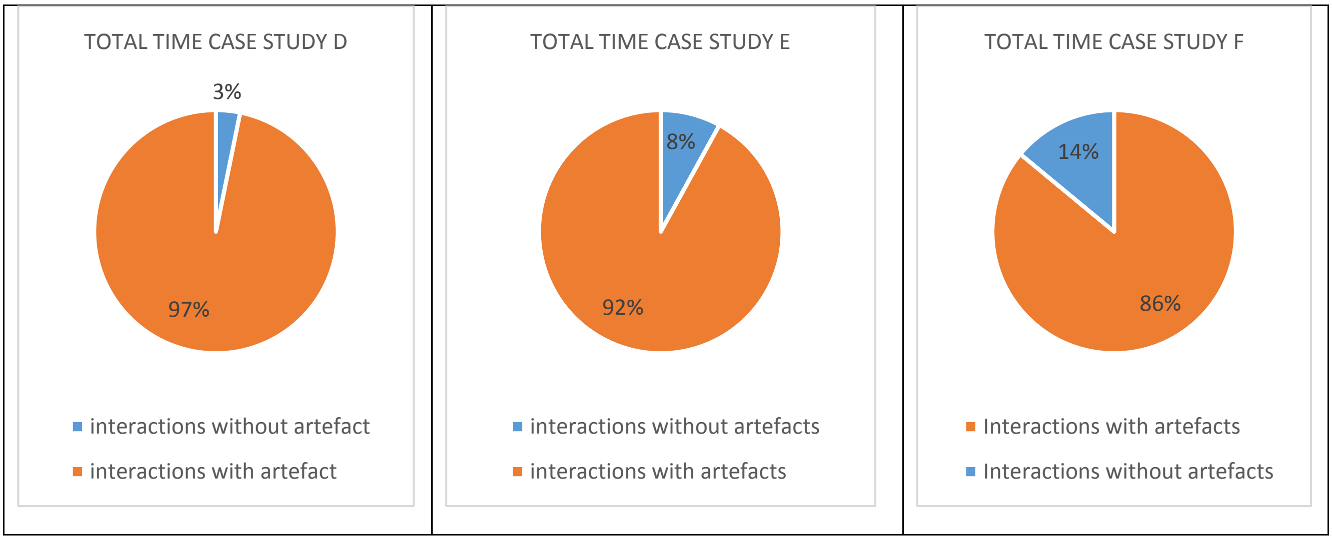


Table 20.Overview of total number of interactions in ICT supported sessions

The parameter of time spent by participants involving artefacts reflects the importance of the design objects. Artefacts support the majority of the interaction time: for case study D, only 1 minute from 35minutes meeting was not supported by any design object. For case study E and F, sessions supported by Spatial augmented reality platform, only 5 minutes of participants' discussion spent without referring to any design artefact.

The use of different technologies does not affect the role artefacts played in collaborative design sessions. Considering meetings with augmented reality or spatial augmented reality platform or even without any ICT tool, artefacts still have a very important place in facilitating communication and supporting interactions between design actors.

2. Second hypothesis

The second hypothesis considers the importance of involving the client/end-user in the collaborative design session. Through the established state of the art, we confirm that the participation of the clients enriches the design process. However, our hypothesis focuses on how the profile of the client affects his participation rate. Therefore, we study the difference of participation rate between real customer of the design company and when the meeting is running with recruited end-users. We formulate the second hypothesis as following:

H2: We assume that the stakeholders' profile (Client or End-user) impacts the rate of interaction: We suppose that the clients interact more than the end-users, since they are directly involved on their own project. Therefore, the interactions in session involving clients will be more dense and richer than when the session runs with end-users who are simple potential target customers.

We present through the following graphs the findings of the different stakeholders' profiles involved in collaborative design meetings supported by ICT tools:

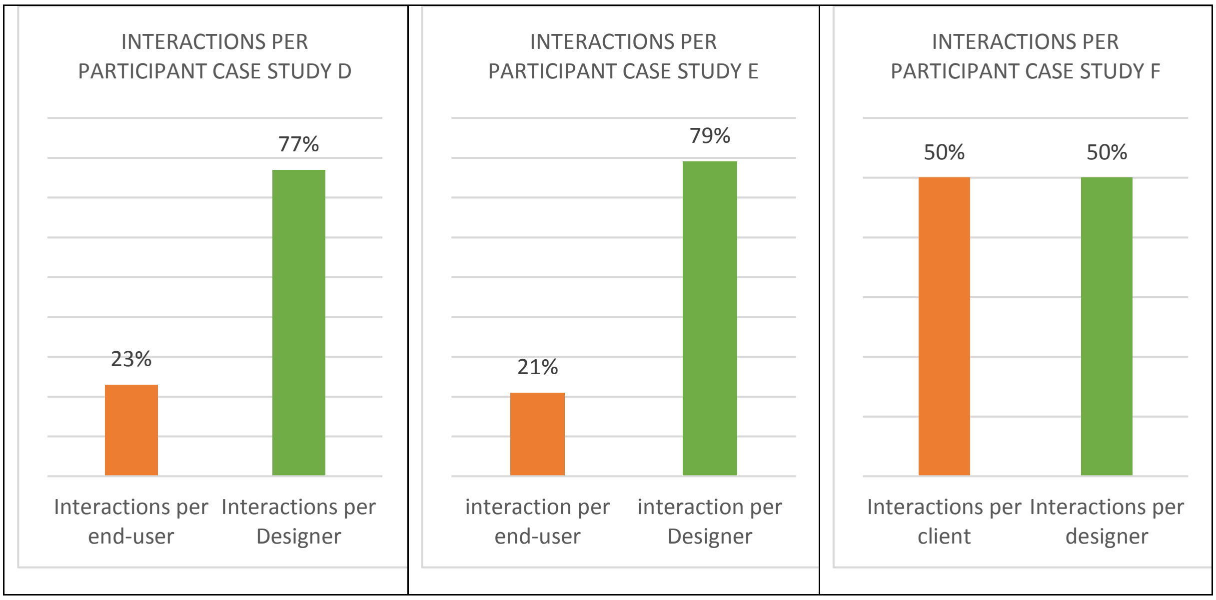


Table 21.Overview of interactions distribution in ICT supported sessions

Concerning the sessions involving end-users, their rate of participation is up to 23% of session time. The participation of clients is more than the double of this percentage. Client's involvement represents 50% of the session's time. The difference of involvement between the profiles is considerable.

Our findings verify again the hypothesis that the difference of profile between client and end-user influence clearly their implication within the collaborative design activity. Designers looking for a high-implicated end user's profile in their collaborative session are encouraged to incite their end-users to be active by using specific method.

4. Findings

This paragraph sums up the most important findings from analysing the observations of collaborative design sessions supported by different ICT tools.

1. Artefacts involvement in sessions supported by ICT tool

Given that artefacts play a crucial role in collaborative design meetings, we have a deep look on their repartitions and percentage of use:

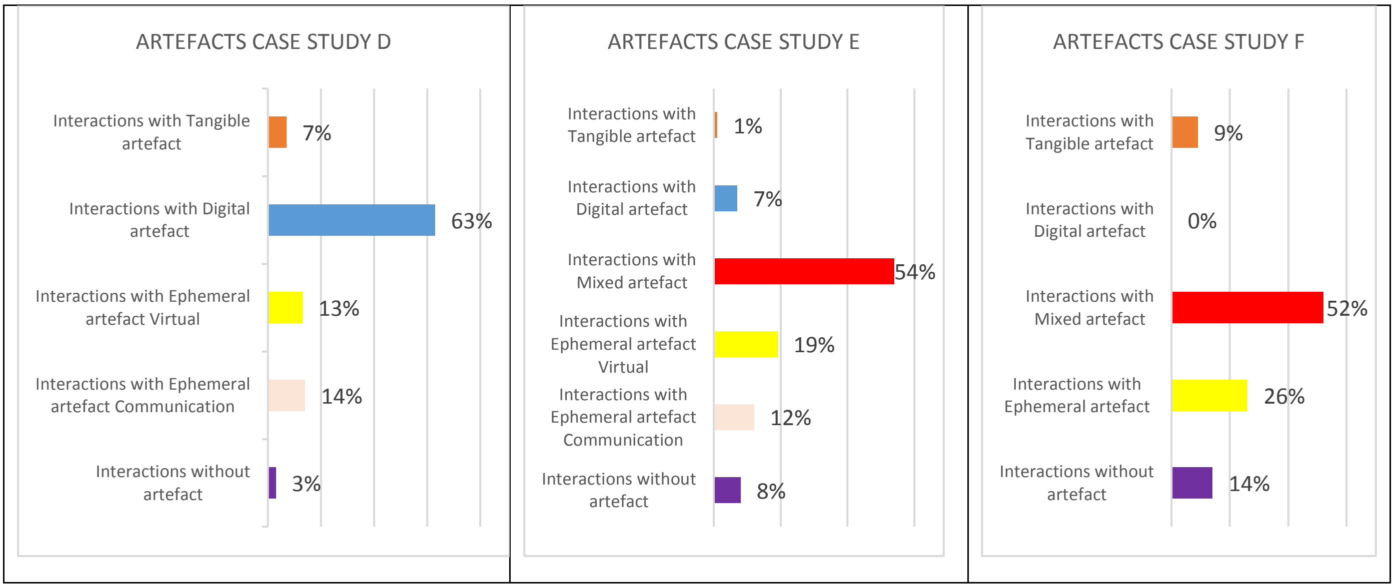


Table 22.Overview of artefacts distribution in supported ICT sessions

The analysis of interactions occurred during collaborative design meetings shows an important involvement of digital and mixed artefacts. The sessions present a similar profile even for case study D that ran with an augmented reality application. For this case study 63% of the interaction time involved digital artefacts and the participants used also ephemeral artefacts for 27%. Case study E shows approximately the same proportion with 54% of mixed artefacts use and 31% of ephemeral artefacts. The last case study is characterised by a high involvement of mixed prototype 52% and same as the previous sessions, the ephemeral artefacts are well involved 26%. The use of tangible design representation is very limited up to only 9%. For sessions supported by ICT tools, participants focus their discussion around the digital or mixed artefacts. In other words, we can assume that mixed artefacts can take the place of tangible artefact as preferred artefacts of design actors. The ephemeral artefact persists in different conditions; in with and without ICT sessions, participants use the gestures to express some of their opinions or to support some ideas.

2. Interaction modalities involvement in sessions supported by ICT tool

For what concerns the interaction modalities, the three sessions present different profiles.

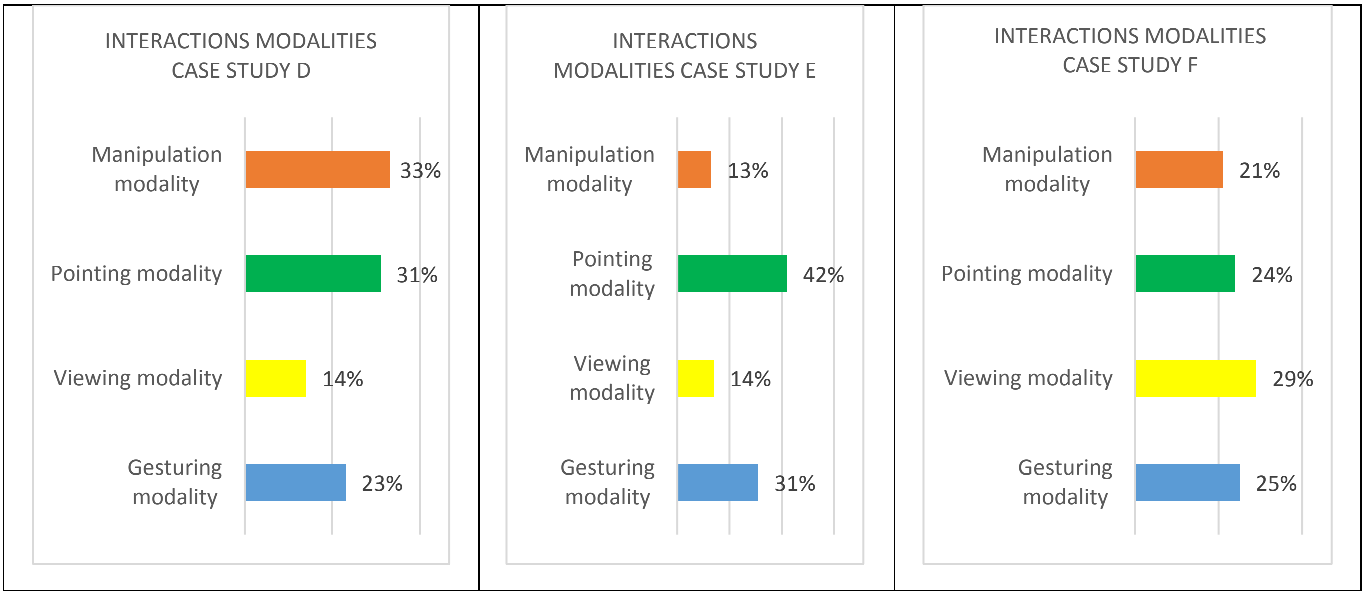


Table 23.Overview of interactions modalities in ICT supported sessions

However, we can classify the sessions as follows:

- Case study D that is supported by the augmented reality application involves manipulation as the mostly used modality (33% of session total time).
- Case study E and F have different preferred modality: 42% of pointing and 29% of viewing. However, these two sessions involve manipulation as the lowest modality used by participants.

We can assume that sessions with an ICT tool encourage the use of shared modalities such as pointing and viewing. Gesturing remains at a significant level whatever the technology, which confirms that this modality is still very important to communicate during co-design sessions

Our findings indicate spatial augmented reality involves more shared modalities (e.g. pointing, viewing, gesturing) that help the communication and exchange between participants in collaborative design meetings. These results encourage the choice of spatial augmented reality in favor of augmented reality in order to foster communication.

3. stakeholders' involvement in sessions supported by ICT tools

As mentioned on the previous section, in our work we give a special focus to the client's involvement in the design activity. In this paragraph, we measure the rate of the client's participation (or end-user) for the three collaborative design meetings supported by ICT tools.

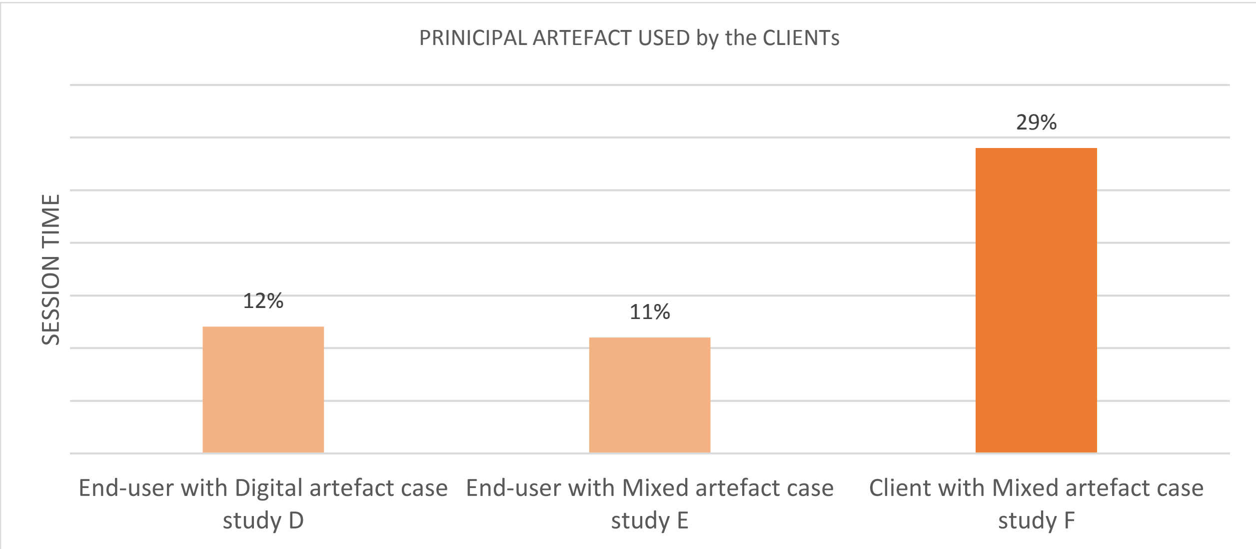


Figure 112.Overview of principal artefact involved by client in ICT supported sessions

The results presented by the graph above show good rates of principal artefact. The session involving end-users presents approximately the same rate of engagement 11% and 12% despite using different technologies. The difference is spotted in case study F where the session is supported by spatial augmented reality but also involving a client who showed a very important interest with 29% of the mixed prototype's manipulation.

With this result, we can consider that the integration of client/end-user in collaborative design meetings is significant; the manipulation rate of principal artefact shows an important involvement in the design task. In another hand, we can confirm our hypothesis that the stakeholders' profile influences his implication during the session (end-users 12%, 11% and client 29%).

4. Density of interactions - Artefacts evolutions in sessions supported by ICT tool

In this paragraph, we draw the sessions' profiles through the artefacts' evolution:

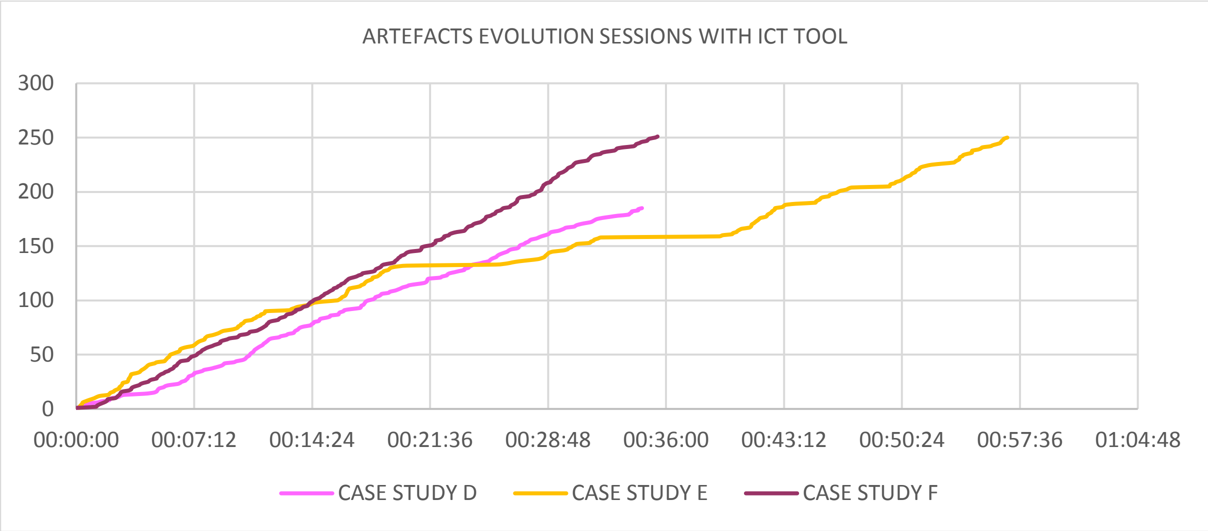


Figure 113.Overview of artefacts evolution in ICT supported sessions

Case study D is the shortest session with 34 minutes. The session D involving augmented reality presents a limited artefacts' evolution. It covers 185 interactions with multiple artefacts with an average of 5.44 interactions every minute.

Case study E presents the longest session 57 minutes. It shows a high rate evolution at the beginning and an important reduction after 20 minutes due a technical issue. However, with two technical issues faced during the meeting the session presents the lowest artefacts' evolution rate. We recorded 253 interactions. Moreover, the average of interaction for this session was 4.43 interactions per minute. This low rate of interactions may be explained by the two platform crashes happened during this meeting.

The last case study F shows the highest number of interactions recorded in ICT supported sessions. This meeting lasted 35 minutes and covered 252 interactions; which brings an average of 7.2 interactions per minute. This session using the spatial augmented reality platform presents a very high amount of interactions per minute. This result is the highest rate of interactions of all sessions and it highlights that using the mixed prototype stimulates the density of interactions.

5. Ephemeral artefacts in sessions supported by ICT tools

We will evaluate in this paragraph the place of ephemeral artefacts in sessions supported by ICT tools.

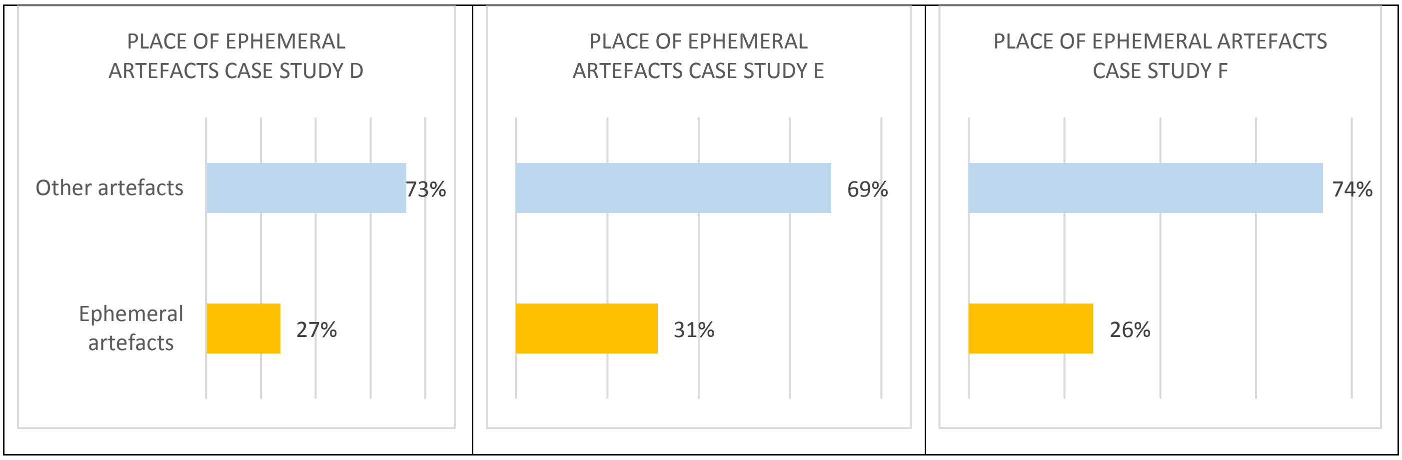


Table 24.Overview of ephemeral artefact involvement in ICT supported sessions

The graph shows the percentages of ephemeral artefacts on sessions supported by ICT tools. The rate of ephemeral goes from 26% to 31%, which represents a good and pretty stable amount of gesturing. We can consider that augmented reality sessions have a good average of communication through gestures in the air. These results show that sessions using ICT tools generate more ephemeral artefacts than standard sessions (see fig. 8); when we introduce a technological support, it incites participants to more express their opinions on design proposals and generates more gestures. This supports the idea that the use of ICT tool facilitates communication in collaborative design meeting through which generates more gestures.

Discussion

The observations' analysis of sessions supported by ICT tools clearly show that when a technological tool is available in the meeting, it attracts the participants' attention. For the three sessions, Digital for case study D was the most used type of artefacts with 63%. For the Spatial augmented reality sessions case study E and F, it is the same case, the mixed artefacts used with 54% and 52% is the favourite tool involved during the discussion. Participants in collaborative design task interact with technological tools when they are available on discussion table. When we introduce ICT tools, participants change their interactions behaviour comparing to standard sessions. They have a very limited contribution through traditional artefacts as tangible design representations, which present a low rate of involvement between 1% and up to 9% of design meeting total duration.

Results show also the significant involvement of ephemeral artefacts as the second mostly used type of artefacts. The percentage of use is approximately the same for the three case studies 26-27% of total time, which means that participants still significantly use ephemeral artefacts to express their ideas through gestures in the air. The technology available do not seem to reduce gestures in the air as one could have expected first.

Let's now look at the interaction modalities used during the three case studies. The results presented above show that case study D stimulates the use of manipulation modality (33%). However, case study E and F present significantly different profile. Manipulation modality presents the lowest rate of interaction for both session (13% and 21%). Contrary to case study D, these collaborative design meetings supported by spatial augmented reality platform favour the use of shared modalities such as pointing 42% and viewing 29%. These interactions modalities request a group attention to share knowledge and exchange information during discussion.

We can explain these results through the sessions' lay out. Indeed, the session based on an augmented reality requires a tablet and a prototype with markers to visualize the result. Only the participant holding the tablet can actually see the evolution of proposal in real time. The other stakeholders only see the physical prototype with the markers. The tablet cannot be shared with other participants on discussion table and it provides a quite limited angle of vision. This set up restricts the possibility for collaboration between different participants in design meeting. On the other hand, the spatial augmented reality setting provides a full vision of the prototype and the ongoing design changes for all the participants at the same time. This significantly improves the ability for collaboration, which is reflected by the figures displayed above.

These results allow us to draw the conclusion that simple augmented reality is not the favourite technology to boost collaboration between design actors. The spatial augmented reality shows an interest on boosting shared interactions modalities and favourites the collaboration aspect in the design meetings.

For what concern the stakeholders' participation, the findings confirm our second hypothesis. The case studies sessions D and E that involve end-users present a limited rate of contribution using principal artefact of the session (12% and 11% of total time (figure 112). The same result concerning the rate of participation during the meeting comparing to the designer, end-users in sessions D and E present a limited involvement between 21 and 23% of session time (table 21).

On the other hand, case study F that involved a client shows an important interest captured through his percentage of use of principal artefact 29%. In addition, the client contributes with 50% of interactions during the session. This percentage reflects the significant implication of the client in the collaborative design task.

This result is reinforced if we look at the interaction rates. The session with clients show, a highest number of interactions per minute (session F) supported by mixed artefact: 7.2 interactions per minute.

This result spots that the use of mixed prototype and the technology of spatial augmented reality stimulates the density of interactions between design actors and encourages collaboration during design task.

CHAPTER III: Global discussion based on Research Questions

Abstract

This chapter presents a discussion based on results of observations of collaborative design meetings. It attempts to answer research questions about how the integration of spatial augmented reality technology enrich the interactions within collaborative design activities. It also aims to highlight the particular effect of spatial augmented reality and it mixed artefacts on clients' implication in the design task.

The reproduction of collaborative design sessions in lab involves many variations of observation parameters. We will consider only sessions held in design agency premises for more robust conclusions. The most important findings to highlight are: The use of SAR prototypes has effect on interactions' evolution; the integration of SAR platform in collaborative design meeting engages more interactions in less time. The SAR improves also the implication of participants through increasing the intensity of interactions during the session. On the other hand, the SAR supported sessions improve the client's implication in the design task through increasing his interactions rate comparing to standard sessions. It also demonstrates an important density of interaction per minute. The use of spatial augmented reality technology enriches the client's contribution.

1. Introduction

In the aim of answering suitably the research questions, we have to select the most relevant sessions from all observations. The meetings in lab environment were reproductions of real situations with implication of recruited end-users. It was not easy to perfectly control all these variables. We made the choice to consider for this discussion chapter only the design meetings held at the design agency premises. Therefore, we will only consider case study A, B and F.

Two reasons conducted us to adopt this approach. First, the designers are emerged in their natural work environment in all the selected cases and the tasks are design tasks of ongoing projects. Second, all the case studies involve the participations of clients of the design company (not recruited end-users), and we saw that this parameter has an important influence on the results already in the previous chapters.

This choice limits the influence of external factors such as the design setting and the participants' profiles.

We structured our discussion on the impact of spatial augmented reality prototype on interactions occurring in collaborative design meetings and the specific effect on stakeholders' participation around the following research questions:

Research Question 1: How the integration of spatial augmented reality platform influences the interactions occurred in collaborative design meetings?

Research Question 2: Does the use of spatial augmented reality prototype has an effect on external stakeholders' participation in collaborative design task?

2. RQ1: Spatial augmented reality Influences the interactions within collaborative design meetings

In order to answer the first research question, we need multiple parameters to evaluate to what extent the integration of spatial augmented reality in a design process can change it and affect interactions between different stakeholders.

1. Place of artefacts in collaborative design sessions:

In standard situation, artefacts hold an important place and participants interact with different types of artefacts. Artefacts support 89% of standard session duration. For what concern the session we insert the spatial augmented reality platform, different artefacts support 86% of interactions between participants.

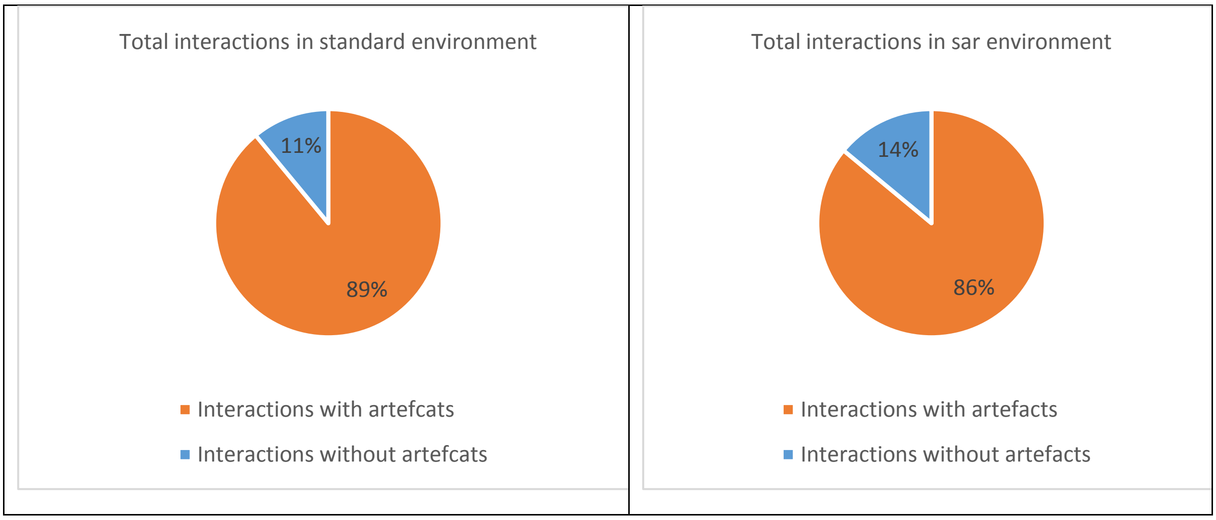


Table 25. Comparison of total number of interactions standard session Vs. Spatial Augmented reality session

The percentage of artefacts involvement is approximately the same in standard session and with session supported by ICT tool. The SAR platform do not show an increase of artefacts used and the design objects are having an important role in the sessions.

We can conclude that even when we use different design representations including or not an ICT support, artefacts still have an important role to support the interactions between stakeholders in collaborative design meetings.

2. Typology of artefacts involved in collaborative design sessions

In this section, we study the repartition of use as well as the nature of the artefacts involved in a standard environment and in a spatial augmented reality one.

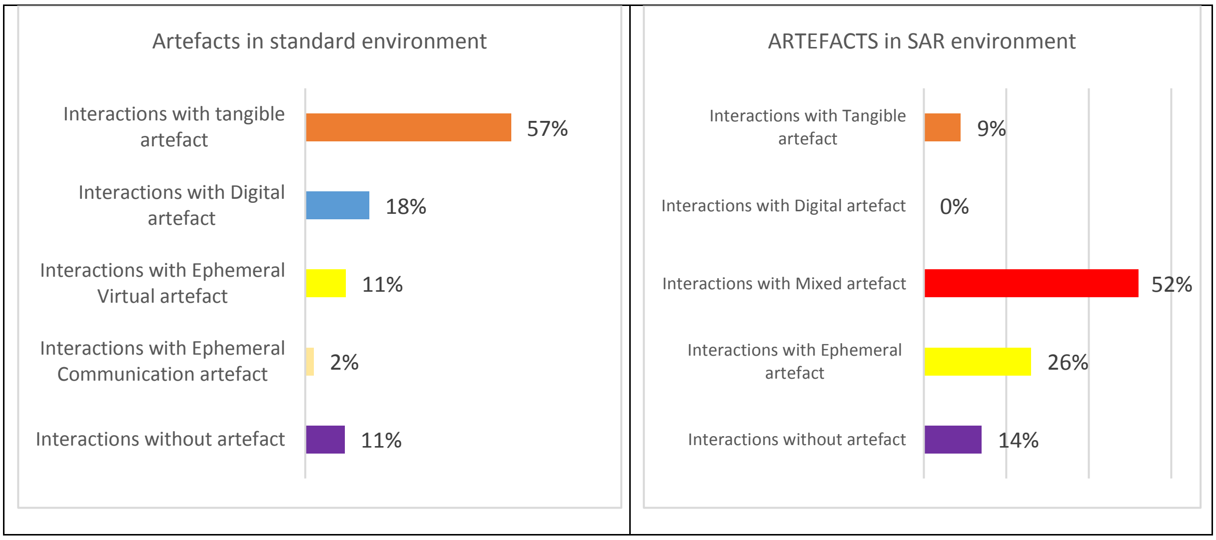


Table 26. Comparison of artefacts distribution standard session Vs. Spatial Augmented reality session

For what concerns the standard session, the most used design representations are traditional design objects such as tangible and digital artefacts. The ephemeral artefacts are involved with a low rate.

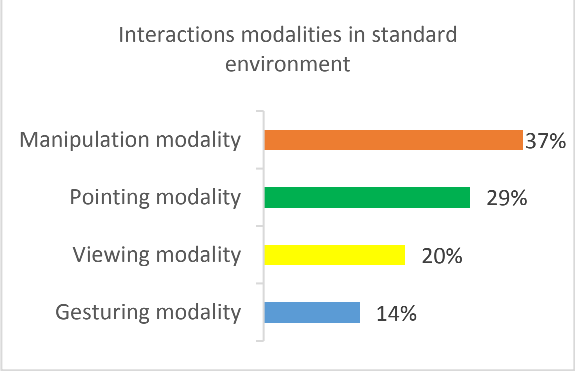
The SAR session present a different profile in term of artefacts used. Participants privilege the spatial augmented reality prototype to interact. Tangible design representations are manipulated with a very low rate and digital ones have completely disappeared. In presence of mixed prototypes, design practitioners do not feel the need to use traditional artefacts (tangible and digital).

Additionally, session supported by spatial augmented reality improves the use of ephemeral artefacts, from 13% in standard session to 26% in SAR supported session. This is a good indicator that communication is improved within SAR sessions given that ephemeral artefacts are facilitators of communication.

We conclude that integrating a spatial augmented reality platform in collaborative design meeting change completely the session's profile comparing to the standard session profile.

3. Typology of interactions modalities involved in collaborative design sessions

In this paragraph, we focus on the interaction modalities used in standard session and if the session supported by spatial augmented reality presents any difference.



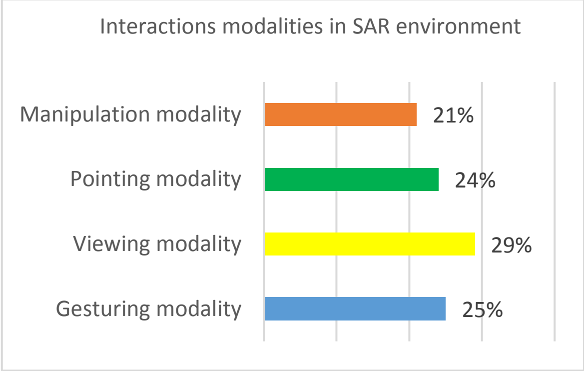


Table 27.Comparison of distribution of shared interactions modalities standard session Vs. Spatial Augmented reality session

As said in the analysis part, the standard session favours the manipulation modality 37%. It involves pointing, viewing and a modest rate of gesturing.

The session supported by spatial augmented reality presents a very different profile of modalities. This session favours viewing modality 29%, good rate of pointing, gesturing, and a less important rate of manipulation.

A deeper analysis has been conducted on the interaction modalities for these cases studies. We focus on spotting the single and shared modalities for each actor. We define the single interaction when participant manipulate, sketch or annotate an artefact without any communication or common interaction with other participants. The aim is to quantify the rate of single interactions for each type of session. We present the findings in the following table 28 with two categories: single modality and shared modalities (gesturing, shared manipulation, viewing and pointing).

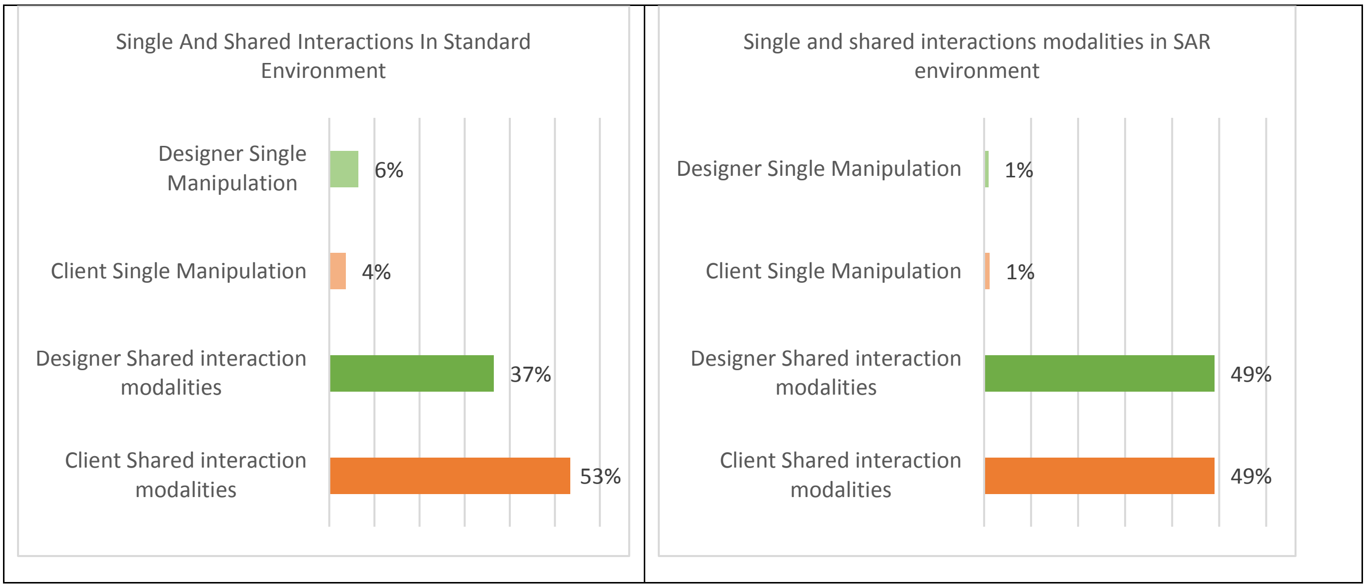


Table 28. Comparison of shared and single interactions modalities standard session Vs. Spatial Augmented reality session

The case study supported by spatial augmented reality improves the use of shared modality viewing, pointing, shared manipulation of objects and gesturing. It decreases the use of rate of single manipulation modality.

We conclude that integrating a spatial augmented reality platform in collaborative design meeting change the session in term of interactions modalities profile comparing to the standard session profile. SAR tends to incite the design group to interact through shared modalities and limit the use of single modality.

This result informs that comparing to the standard situation, the integration of spatial augmented reality improves the collaborative aspect in design sessions through the limitation of single modality involvement. Therefore, we can confirm that SAR stimulates collaboration and encourages participants to collaborate more through the shared modalities.

4. Combination of artefacts and interaction modalities for participants:

The main objective of this paragraph is to characterize the types of interactions that occur within collaborative design sessions between participants with artefacts and through interaction modalities. We aim to understand what design practitioners perceive to be the most important design representations and modality used in collaborative design sessions.

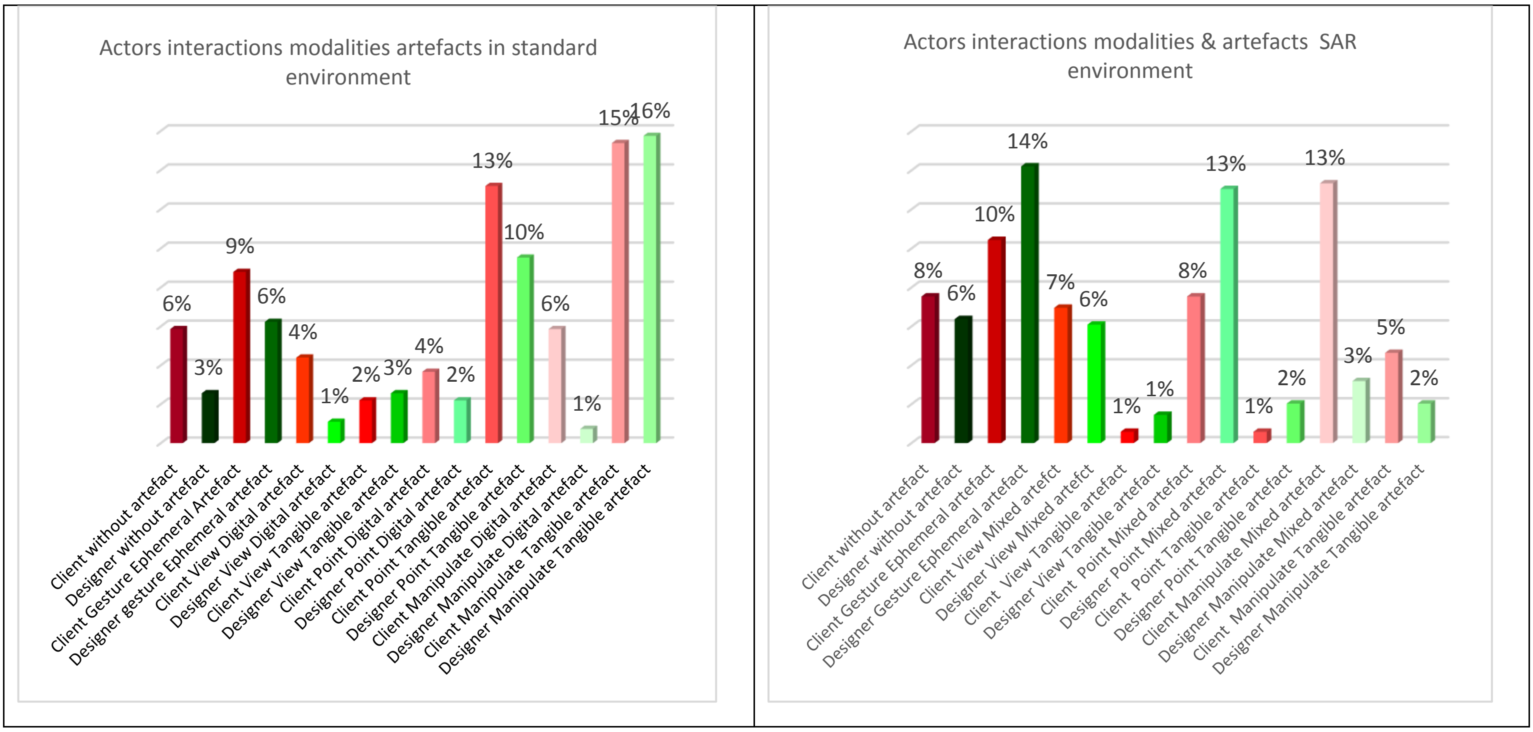


Table 29. Comparison of combination of interactions modalities and artefacts used in standard session Vs. Spatial Augmented reality session

The standard session presents a profile with concentration around tangible artefacts through manipulation: sketching, annotating and holding the prototype.

The case study supported by spatial augmented reality stimulate the use of mixed artefact through the pointing and viewing modalities.

The overall comparison between the two sessions shows that session supported by SAR tends to decrease the use of single modality on principal artefact: In standard situation, the designer spends 16% of total time manipulating the tangible artefact. The client manipulates the tangible artefact during 15% of the meeting. When we insert the SAR tool, the manipulation of principal artefact decreases for all participants. We observe that the designer manipulates the mixed artefact only 3% of the time and the client manipulates the mixed artefact 13%.

On the other hand, we observe shared modalities like viewing involved by designer 3% and 2% for client when they use the principal artefact. Once we insert the SAR prototype, the shared modalities increase remarkably; the designer involves viewing mixed artefact 6% and client with 7% of total time.

Another point to mention is the boost of ephemeral artefacts between standard session 6% for designer and 9% from client to an important rate in session supported by SAR tool 14% for designer and 10% for client. The increase of gestures artefacts is a good indicator for communication improvement in session with SAR platform.

From this section, we conclude that case study using SAR technology presents a different profile of artefacts involved. It favours the use of the technology to collaborate around the mixed artefact. Participants conduct their discussion with a strong involvement of mixed prototype and decrease the use of traditional design representations of tangible and digital tools.

Session based on spatial augmented reality improve the shared modalities used. We can assume that SAR prototype help the group collaboration with this improvement and the limitation of single modality.

The increase of ephemeral artefacts within SAR session stimulates the communication aspect between designer practitioners.

5. Interactions evolution in collaborative design sessions:

The following graph draw the evolution of each session in term of interactions. We aim to evaluate the impact of spatial augmented reality prototype on interactions density and evolution comparing to standard session:

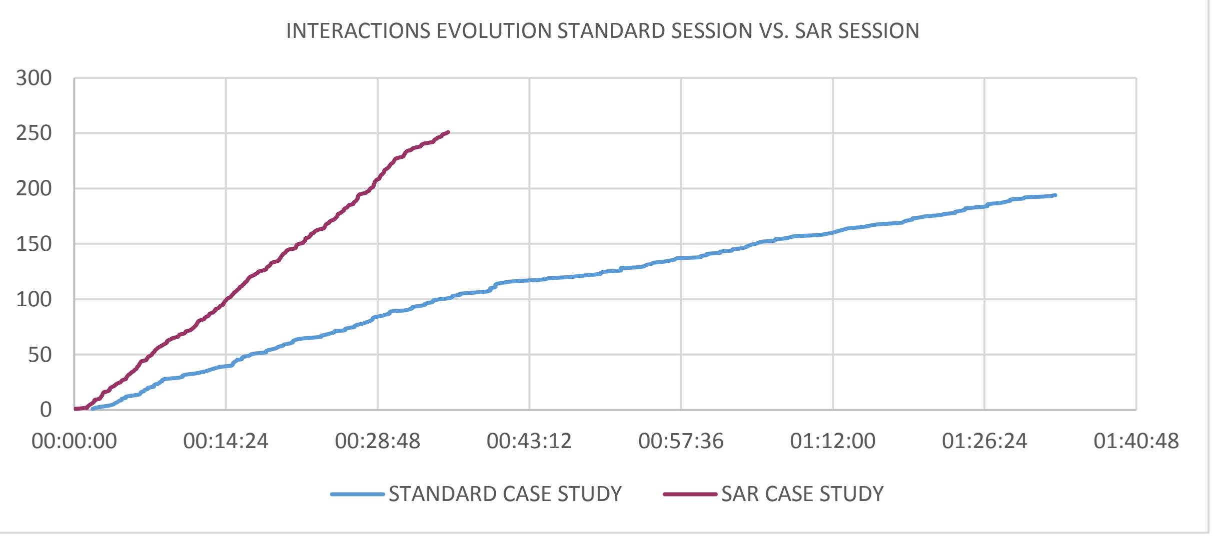


Figure 114.Evolution of interactions in standard session Vs. Spatial Augmented reality session

The standard case study presents a lower profile in terms of interactions' evolution. This session lasted 1h33 minutes and involved 204 interactions. The density of interaction in standard session is 2.19 interactions per minute.

SAR Case study shows a higher rate of evolution. The duration of SAR session is 35 minutes and generate 252 interactions. The density of interaction in SAR session is 7.2 interaction per minute.

The duration of session supported by SAR platform is inferior to the standard session but it generates more interactions (252 Vs. 204).

We conclude that the mixed prototype helps the design participants to interact more in less time.

A remarkable difference between the densities of interaction per minute between both sessions. The SAR session helps the design actors to generate interactions 3 times more than the standard session. Meeting equipped by spatial augmented reality prototype encourage the communication between participants and stimulate the progress in their design task through generation of an important number of interactions.

3. RQ 2: Spatial augmented reality influences the stakeholders' participation within collaborative design meetings

In this section, we try to answer the second research question through the investigation of the spatial augmented reality prototype effect on client's participation in collaborative design meeting.

1. Client's implication in use of principal artefact in collaborative design sessions

This paragraph spots the importance of client involvement of principal artefact in each session. We present the following graph to evaluate the client rate of implication over the total session time:

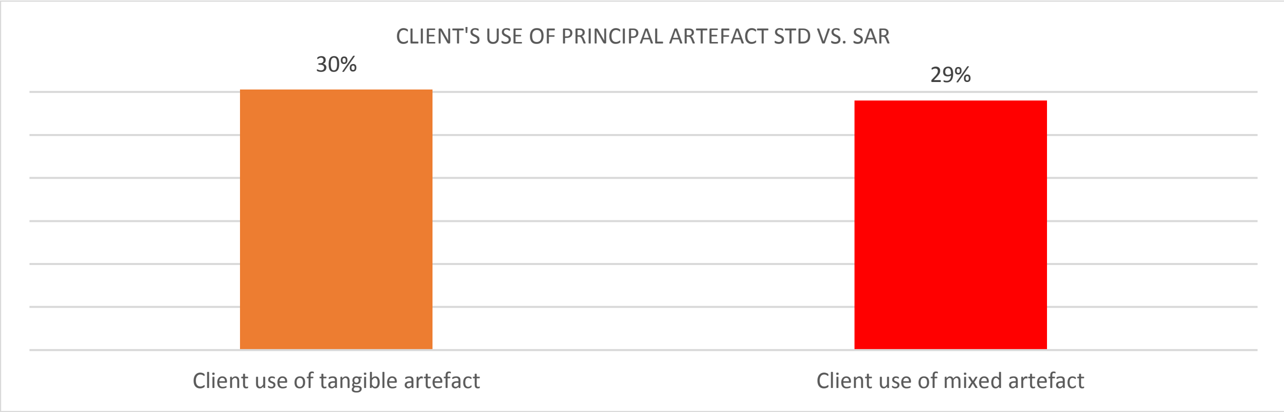


Figure 115.Overview of principal artefact involved by client in standard sessions Vs. Spatial augmented reality session

The client's rate of participation is approximately the same for both sessions. The SAR prototype keeps almost the same rate of implication of client in the design task.

We will have a deeper look in the repartition of artefacts within the client own time. In order to evaluate if the SAR prototype incites the client to interact more:

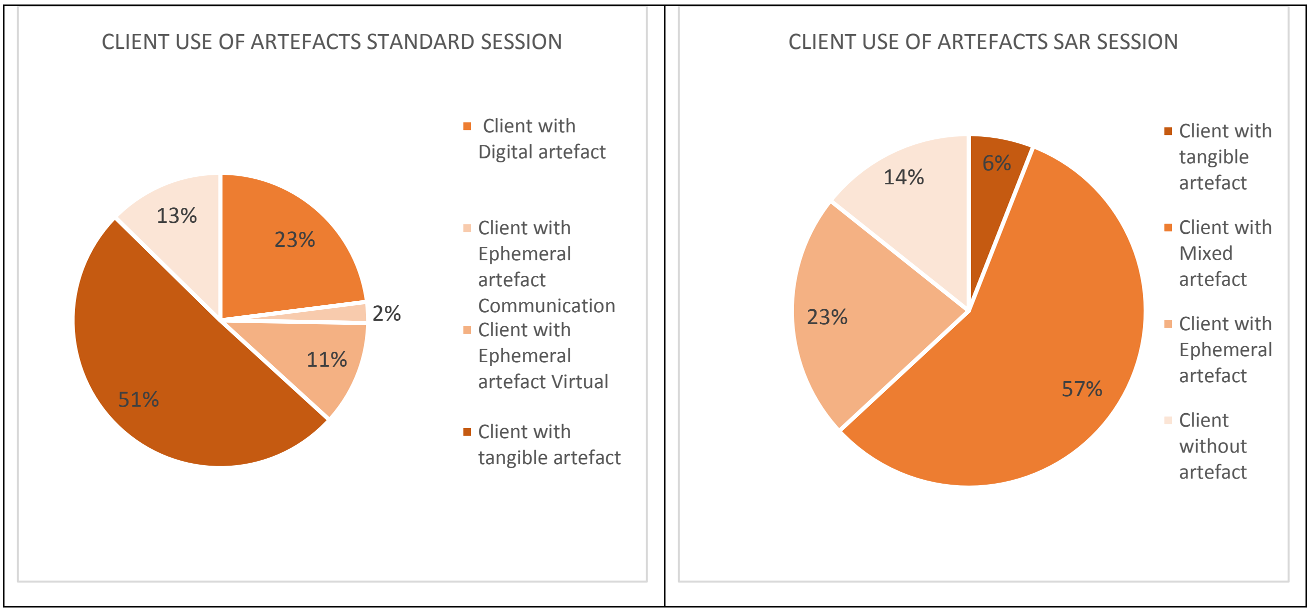


Table 30. Distribution of artefacts used by the client in standard session Vs. Spatial augmented reality session

The graphs show that in standard collaborative design session client uses principally the tangible artefact with 51% of his total own time. In meeting supported by SAR prototype, the client interacts mainly with mixed artefact 57%. There is a slight improvement on the client interest in using the SAR prototype comparing to the tangible representations.

We conclude that inserting the mixed artefact, the prototype of spatial augmented reality platform, it incites more the client to use it. A modest improvement is observed comparing to standard design representations.

2. Client's implication in use of ephemeral artefact in collaborative design sessions

As presented in the state of the art, the ephemeral artefact is considered as a communication tool. The designers use the gestures to support their ideas and explain more explicitly their needs(Davis, 2016).

We will now investigate the rate of ephemeral artefacts involved by clients. The following graph presents the percentage of gestures used in standard and supported by SAR prototype sessions:

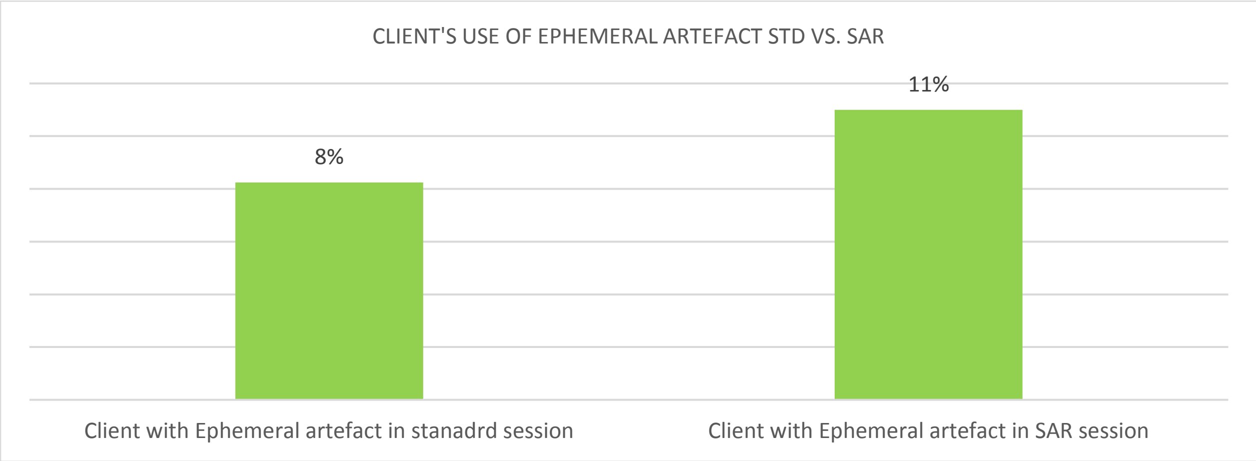


Figure 116.Overview of ephemeral artefact involvement in standard sessions Vs.Spatial Augmented reality session

The client's rate of ephemeral involvement in standard session is limited to 8% of meeting total time. Once we integrate the spatial augmented reality platform, the client shows an improvement of gestures up to 11% of session's total time.

Hereafter, we show the repartition of client's own time in term of artefacts used in both sessions:

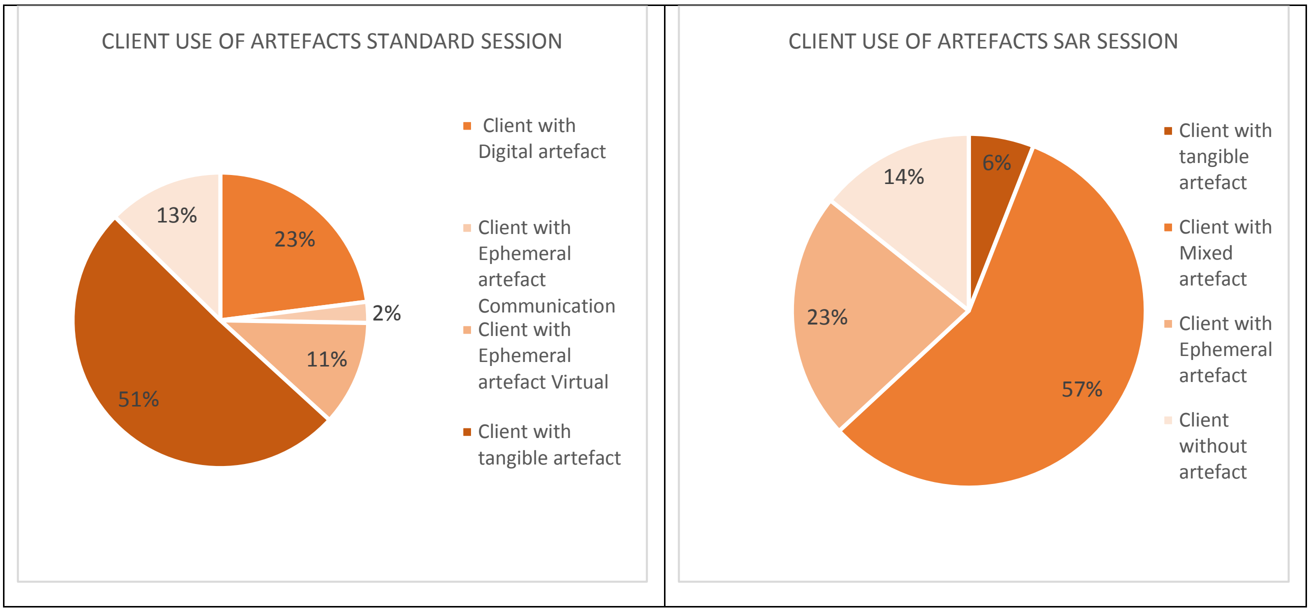


Table 31.Distribution of artefacts used by the client in standard session Vs. Spatial augmented reality session

In standard situation, the ephemeral artefacts used by client is 13% of his own time. In session supported by SAR platform, gestures shows a good improvement and recorded 23% of client's own time.

We conclude that spatial augmented reality enhances the communication between participants through the boost of ephemeral artefacts from the client side. SAR platform helps the client express more his ideas and support his thoughts.

a. Client's intensity of interactions

Session	Duration	Number of client's interactions	Client interactions per minute
Standard Case study	96 minutes	87	0.93
SAR Case study	35 minutes	84	2.4

Table 32.Client's intensity of interactions

As mentioned before, the standard session lasted 1h33minutes and involved 87 interactions from the client's side. The density of client's interaction in standard session is 0.93 interaction per minute. SAR Case study duration is 35 minutes and the client generates 84 interactions most of them are supported by the mixed artefact. The density of interaction in SAR session is 2.4 interactions per minute.

We observe that the duration of session supported by SAR platform is two times shorter than the standard session but client generates approximately the same number of interactions (87 Vs. 84).

This result clearly shows an important privileged environment within SAR session improving the client implication. This context encourages the client to interact more and be more productive in collaboration design activity.

CONCLUSION OF PART III

We can summarise the results gathered in this chapter as answers to our research questions. We present the most important points as follow:

- Research Question 1: How the integration of spatial augmented reality platform influences the interactions occurred in collaborative design meetings?
    - The integration of spatial augmented reality prototype keeps the importance of artefacts in collaborative design session. Same as standard sessions, artefacts still play a crucial role as an important support for collaborative design interactions.
    - The integration of spatial augmented reality technology in design meeting changes the sessions' profiles regarding the artefacts used. It fosters the collaboration around the technological tool and limits the use of traditional design representations.
    - SAR prototype improves the ephemeral artefacts within collaborative design meetings. This indicates an improvement of communication between design stakeholders.
    - SAR brings changes in interactions modalities profile. The SAR impacts the interaction modalities by improving the shared modalities and limiting the use of single modality of artefacts manipulation. The boost of shared modalities encourages the collaborative aspect in these design meetings.
    - The use of SAR affects the interactions' evolution: results demonstrate that the integration of SAR platform in collaborative design meeting improves the interaction rate. This indicates an improvement of the communication among the design practitioners.

- Research Question 2: Does the use of spatial augmented reality prototype has effect on stakeholders' participation in collaborative design task?
    - Measuring the involvement of principal artefact in each session, meeting supported by SAR tool shows a slight improvement of client's implication through the mixed artefact. We assume that the technology attracts more the client and incites him to be more engaged than with standard design representations.
    - The rate of ephemeral artefacts increases within the session supported by SAR. Considering gestures as a way to support communication, SAR provides a better support for design communication than standard means, both for clients and designers.
    - SAR supported session improves the client's implication in the design task through increasing his interactions rate compared to standard session. This indicates a clear improvement in the activity during SAR sessions.

These results show that the integration of SAR technology influences the interactions occurring in collaborative design sessions. It stimulates the communication between design actors and boosts the client implication. SAR presents a favourable environment for collaboration between different design stakeholders.

Through this chapter, we have discussed the results of the analysis phase. We draw our research work conclusions. We spot the impact of spatial augmented reality on design interactions within collaborative environment. We also qualify the technology as facilitator when stakeholders contribute in the design task. The next and the last part discuss the contributions and limitations of this research study.

GENERAL CONCLUSION

In this thesis, we proposed an approach for analysing the impact of integrating an innovative technology such as Spatial Augmented Reality in a collaborative design process involving external stakeholders. In order to assist this integration, the SPARK platform, developed within the European project SPARK, has introduced and served as a basis for the development of this thesis. The project aimed at developing a responsive ICT platform that brings the potential of Spatial Augmented Reality to enhance the collaboration in design process by reducing language barriers between different design team members.

External stakeholders, such as clients of the design agencies or end-users of the products are two types of population we studied in this thesis. These populations fall in the category of "users" and we saw that they behaved very differently so that it is interesting to adopt a more refined categorization of actors when considering the development and integration of SAR technology in the design process.

In this thesis, we intentionally focused our interest on the role design artefacts play in collaborative design meetings. This has been a long-encstanding tradition in the collaborative design team to focus on artefacts produced by the designers in their everyday activity. Artefacts are the visible and tangible outcome of these design activities, which are mainly cognitive and therefore not easily observed. In the case of augmented really, we have seen through the literature review, that the technology potentially provides means to create a great variety of new artefacts with interesting characteristics, among which versatility is not the smallest one. We used the SPARK platform to investigate the integration of such a SAR tool and how it can influence the interactions and help external stakeholders to be more involved in the design task.

We have carried out a set of experiments in a controlled environment reproducing the industrial setting of our industrial partner. Through this controlled study, we want to check if the use of SAR foster the design task comparing to the conventional way of work. The first results were encouraging, and we assume that this innovative technology enhance the communication between design participants.

Our approach considers the collaborative design process as a social and technical knowledge intensive process. Its social aspect comes from involving internal and external stakeholders, which is qualified by the previous research studies as an important added value to the design task. However, this last point may imply difficulties such as problems of misunderstanding of the end users' needs or requirements. The technical aspect involves the choice of an adequate tool for collaborative context. The technology should stimulate communication between different design actors and try to enhance the external stakeholders so their contribution can be beneficial to the design process. Our elaborated state of the art suggests Spatial Augmented Reality might be a suitable technology to support collaborative design interactions.

Based on the elaborated state of the art, we set a methodological framework based on design protocol analysis method. In addition, we define an analysis framework based on a gestures and artefact centric analysis. This framework allows the elaboration of analysed data in order to answer the questions related to the profile of actor initiating the design interaction. It is also related to the typology of artefacts involved, whether they are tangible, digital, mixed or a gesture, and finally the nature of interaction modalities engaged by the design actors (Manipulation, pointing, gesturing or viewing). The application of this analysis framework relied on six case studies involving design teams with different stakeholders' profiles (clients and end users).

Our main contribution is highlighting the impact of SAR technology as a booster of collaborative design interactions and qualifying the SAR technology as facilitator of communication when we involve external stakeholders in the design task. These conclusions were drawn thanks to the following findings:

- From the collaborative design interactions point of view:
    - Integration of the SAR technology preserves the important role played by design artefacts in supporting collaborative interactions. Moreover, it tends to improve the interaction rate between participants comparing to standard sessions.
    - SAR also changes the design sessions' profiles introducing a preference for mixed artefacts comparing to the other more conventional artefacts.
    - SAR improves communication through the enhancement of gestural artefacts
    - SAR technology enhances the shared modalities use and limit the involvement of single modality therefore encouraging the collaborative dimension.
- From the external stakeholders' perspective:
    - Clients and end users' interaction rate is improved while using SAR technology.
    - Stakeholders involve more gestural artefacts, which is a good indicator of stimulated communication.
    - We distinguish two interaction profiles between clients and designers.

We consider that our contribution, based on various observations, reveals that integration of SAR technology enhances collaborative interactions occurring in design sessions. It has advantages over the stimulation of communication between design actors. We demonstrated that SAR boosts the external stakeholders' implication, and we highlighted the various profiles of interaction depending on the type of stakeholder. This information is important for future developments of collaborative environments as we characterised the need for supporting different types of interactions. Nevertheless, we consider that SAR technology presents a favourable environment to run collaborative design activity.

In conclusion, thorough this thesis, we described design interactions in collaborative context and then demonstrate that SAR offers the possibility to enhance these interactions and consequently foster the communication between design team members despite their different backgrounds. Especially we showed that external stakeholders, clients or end users were positively responding to the mixed artefacts and interacted more in proportion than with traditional media. In addition, questionnaires and interviews carried out by other teams of the consortium(O'Hare et al., 2018) acknowledge that SAR is not intrusive and the user experience was quite positive for the participants of all our tests.

The next steps of this work is to make complementary validations of the concepts proposed in this thesis. Considering the time dedicated, the three years did not allow performing additional observations. It seems to us essential to carry out further formal qualitative evaluations or assessments based on our adapted tool. Our research study has brought out some possible new research fields to investigate. In this paragraph, we discuss our perspectives and possible future steps following this research study.

From the research methodology perspective, the observation of case studies ensures a qualitative deep understanding of the design activity, which allows the researchers to establish adequate tools supporting design interactions. However, this methodology including capture and analyses of data is known for being too much time consuming. Thus, suggesting a methodology enabling analysing data while being captured (on the fly) will be an innovative idea, which will improve the traditional way of design protocol analysis. A tool has been tested during the SPARK project (ref ICED observer) and future work would be to use it extensively on captured data in order to be able to carry out quantitative analysis.

On the other hand, the findings show interesting results when involving SAR tool within collaborative design sessions in term of shared modalities. As a first option, we can carry out further research studies to determine the factors that reinforce the use of shared modalities.

We would like to complete other studies on the collaborative aspect. Our research context was limited to a static participant (user in fixed position) in small groups. We need to carry out studies on other collaborative frameworks involving a large number of participants, in a standing position (wall frame) or even in remotely position meetings. Another aspect seems interesting to us is the spatial lay out: studying the impact of orientation and the comparison of face-to-face vs. side-by-side collaboration are worth being considered.

We also can envisage to connect gestures to cognitive functions and try to unfold the cognitive mechanisms that sit behind the gestural and verbal interactions. For that we need to complement the analysis with verbal interaction coding.

On the other hand, we can focus our research studies on the technical improvement of our supporting tool that can improve the experience of design actors:

- From a visualization point of view, a detailed research on video projectors proprieties or a table projection would provide a better quality system especially if we can improve the calibration procedure so that the experience of visualization gets closer to the real products. The platform is not a plug and play tool; the user should be more assisted in the setting up procedure.
- We strongly believe that other interfaces need to be experimented such as larger tactile screens or new haptic systems. Additional experiments should be conducted to evaluate the most suitable interface and interactions adapted. A study of 3D interaction modalities with SAR interfaces is a next step in our work. Our initial goal being oriented towards a user-centric approach, a more detailed analysis of the results obtained will allow drawing some design principles dedicated to collaborative 3D interaction interfaces easily adapted by non-designer public.

Based on our work results and taking into account the importance of the collaboration aspect, we encourage further research studies to continue exploring the features of new technologies such as SAR to help improve designers’ work condition. However, future works should design more adapted interfaces and carefully implement useful collaborative creation tools in order to preserve human communication and interaction instead of machine watching.

APPENDIX

Appendix A

Agreement to participation

Participant will sign consent to participate at each session and will have the opportunity to ask any question they want.

INFORMED CONSENT TO PARTICIPATE

IN A RESEARCH PROJECT STUDY

Research project Title: SPARK - Spatial Augmented Reality as a Key for co-creativity

Project Coordinator: Gaetano Cascini

Person in charge of conducting the studies: [It will change according to the tests and the people involved] :

PURPOSE OF THE STUDY

You have been asked to participate as a subject in a research project study about the creativity and the use of Spatial Augmented Reality for increasing the creativity in design collaborative sessions. In particular this study will focus on the analysis of interactions during co-creative session with clients. More precisely our aim is to characterize and evaluate the types of interactions the participants have with physical or digital artefacts in co-creative sessions.

You have been asked because you are at least 18 years of age and a designer/ a customer of a design studio/a design/engineering student at Politecnico di Milano / a possible user of the SPARK platform.

Please note also that the final aim of the project is to commercially exploit the SPARK platform.

PROCEDURES

If you choose to participate in this project, you will be asked to perform a task possibly involving the use of Spatial Augmented Reality technologies related to co-creation and decision making.

The procedure will include the recording of co-creative design sessions where you are involved as a participant in your natural working environment.

During the post-test session, which will last 20 minutes, you will be debriefed and qualitative data about your preference for the human-machine interface and impression will be collected.

RISKS AND DISCOMFORTS

The risks to you as a participant in this study are not greater than what would be encountered in everyday life. There is however a risk of discomfort due to the presence of cameras and microphones.

BENEFITS

There are no direct benefits to you as an individual. However, your participation will help with the contribution of knowledge to the society and the scientific community; knowledge deriving from the testing results will be useful for designing better the SPARK platform so as to improve its impact on creativity.

COMPENSATION OR COSTS TO STUDY PARTICIPANTS

Refreshments in the form of snacks will be provided at the end of the test session to show our appreciation to you for volunteering for the study. You are free to decide whether or not to take it. The study is free and voluntary; therefore, there will be no cost involved in participating. Also, the study involves no risks for injury; therefore, there will be no compensation for injury.

CONFIDENTIALITY

All information collected in this test will be kept completely confidential to the extent permitted by law. Efforts, such as coding of research records, keeping research records securely on a password protected computer information system, and allowing only authorized people to have access to research records, will be made to keep your information safe. A report of general and combined results from several participants in this project will be prepared, and may be submitted to a professional publication or conference at a later time. The data used for publication will be strictly anonymized. All information obtained during this study by which you could be identified will be held in strict confidence, and kept for five years after the study.

INCIDENTAL FINDINGS

In general, ***Incidental findings*** are previously undiagnosed medical or psychiatric conditions that are discovered unintentionally and are unrelated to the aims for which the tests are being performed. The Consortium has as primary purpose to respect participant's integrity, autonomy and rights and to act in the respect of the best interest of the participants involved in the tests. Therefore, The Consortium will ask you to decide and declare in the following if you want to be informed or not about possible incidental findings related to yourself.

QUESTIONS ABOUT THE STUDY

If you have any questions about your involvement in this project, you may directly ask the person in charge of conducting the test or the project coordinator, Prof. Gaetano Cascini, at the following e-mail address: gaetano.cascini@polimi.it

VOLUNTARY PARTICIPATION/WITHDRAWAL

Your participation is voluntary, and you may end your participation at any time. Refusing to participate or leaving the study at a later time will not result in any penalty or loss of benefits to which you are entitled. Your grade, record, academic standing, or relationship with the University will not be affected if you choose not to participate or withdraw.

Each person participating in the study will be asked to complete the following:

	Y	N
1. Have you read the information sheet?	☐	☐
2. Have you had the opportunity to ask for more information about the study?	☐	☐
3. Are you happy with the answers to any questions you had, if any?	☐	☐
4. Do you understand that you are free to withdraw from the study at any time?	☐	☐

5. Do you agree to take part in this study? ☐ ☐

6. In the remote possibility that incidental findings will be discovered, would you like to be informed? ☐ ☐

Signed (Participant)………………………………………………

Print Name (Participant)…………………………………………… Date………………

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