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Cars with an Intent

Envisioning new car-to-human and human-to-human relationships through autonomous cars' interfaces

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ABSTRACT

In a near future autonomous cars will likely populate the urban environment together with traditional cars and other road users. While they will actually consist of urban- scale robots immersed in a socio-technical context, so far autonomous cars have been almost exclusively looked at from the perspective of safety and functionality and they have not been designed towards acting as social urban beings. "Cars with an Intent" is a design- research driven PhD project which envisions cars beyond their core objectives of functionality and safety, and probes how positive and enriching car-to-human and human-to-human relationships can be prompted by embedding social intentions and behaviours in the car. After an initial exploration in the two different directions, the research delves into the specific concept called "Co-Drive", pursuing human-to human relationships. First, I describe the Co-Drive concept as an extended reality experience (XR); next I develop an early-stage prototyping methodology that allows me to test it with real people in their context without having the fully developed technology. Through three prototyping interventions, I draw the first conclusions on the social values of the "Co-Drive" concept and I suggest that the social intent of autonomous cars may emerge through i) teledriving, as a combined intent between the autonomous car and the human; and ii) the in-car interfaces, as a way to spot and board remote passengers and to embody them in the car.

"You never change things by fighting the existing reality.

To change something, build a new model that makes the existing model obsolete."

B. Fuller

Acknowledgments

Many people need to be thanked by myself because spent their resources, their time, their knowledge and their curiosity on me and the project. 2 persons go first: my supervisor Pino (alias prof. Giuseppe Mincolelli), who unconditionally trusted me and my research intuitions, and my friend Emanuele Ruffaldi, who advised the project since the very initial idea in 2017. Then I thank all the participants who prototyped the idea with me at the day-care Cooperativa Nuova Socialità in Rome, and the amazing collaborator I found there, Gianluca Boccia. Giusy always welcomed my ideas and brought them to the day-care centre, making me feel part of the group. Paola Cesaretti was key at the beginning of the project. I thank Ericsson R&D Italy Innovation Garage, in particular Simone Bertucci, Fabio Pes, Marco Garofoli, Lorenzo Gammarota, Alessandro Pane and my first lucky contact Peter Marshall. I hope that our collaboration will go on beyond Co-Drive! Thanks to Marcello Carrozzino from Scuola Superiore Sant'Anna di Pisa for his initial support and his student Gianmario Cabizza who helped in the very first version of the Atlas.

I thank my family for support, patience and continuous inspiration and I ask Romeo, Guia and Giovanni to forgive me for the extra time I devoted to my research. I hope that studying and researching on this PhD topic have made me into a better human being they could keep enjoying being surrounded by.

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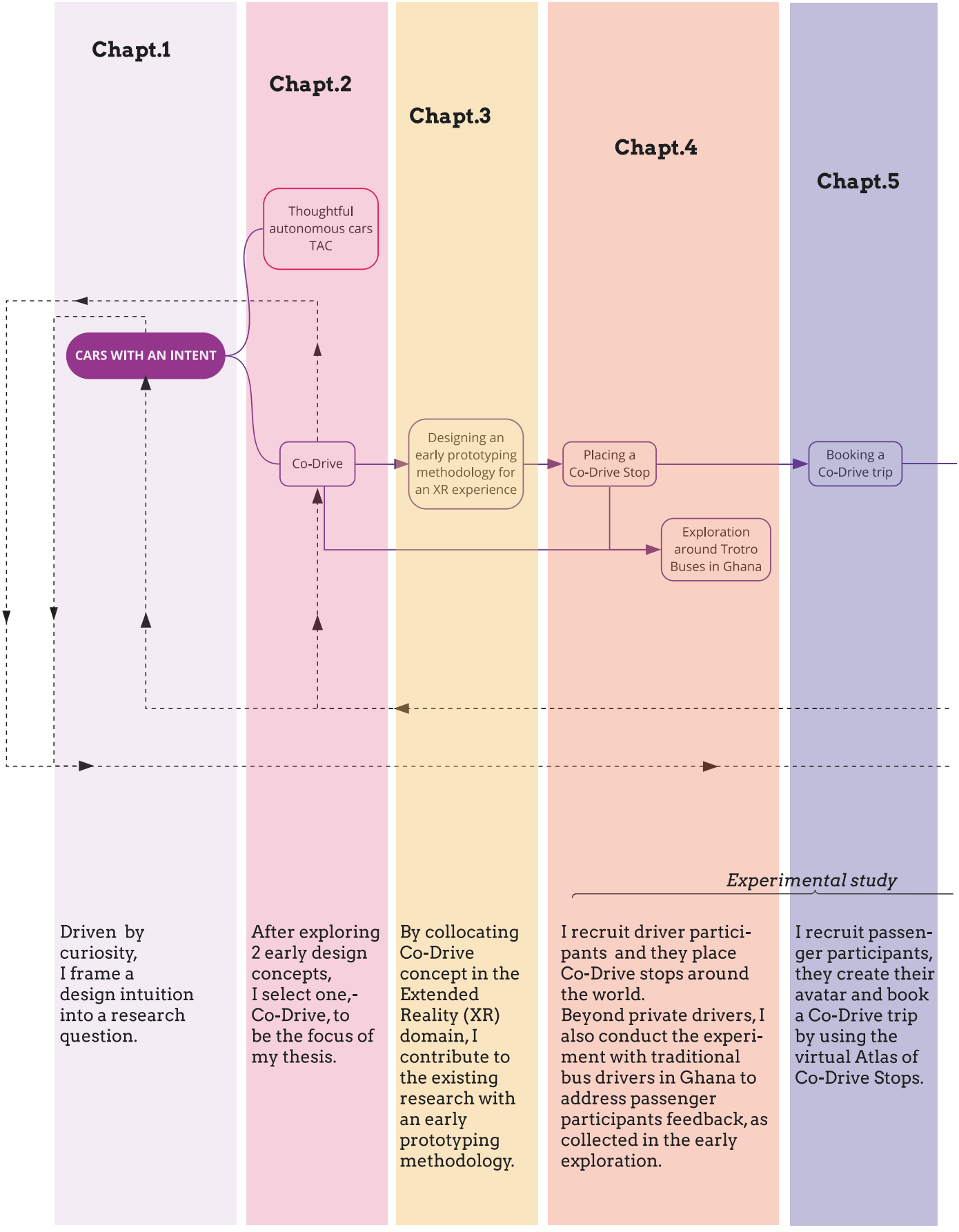
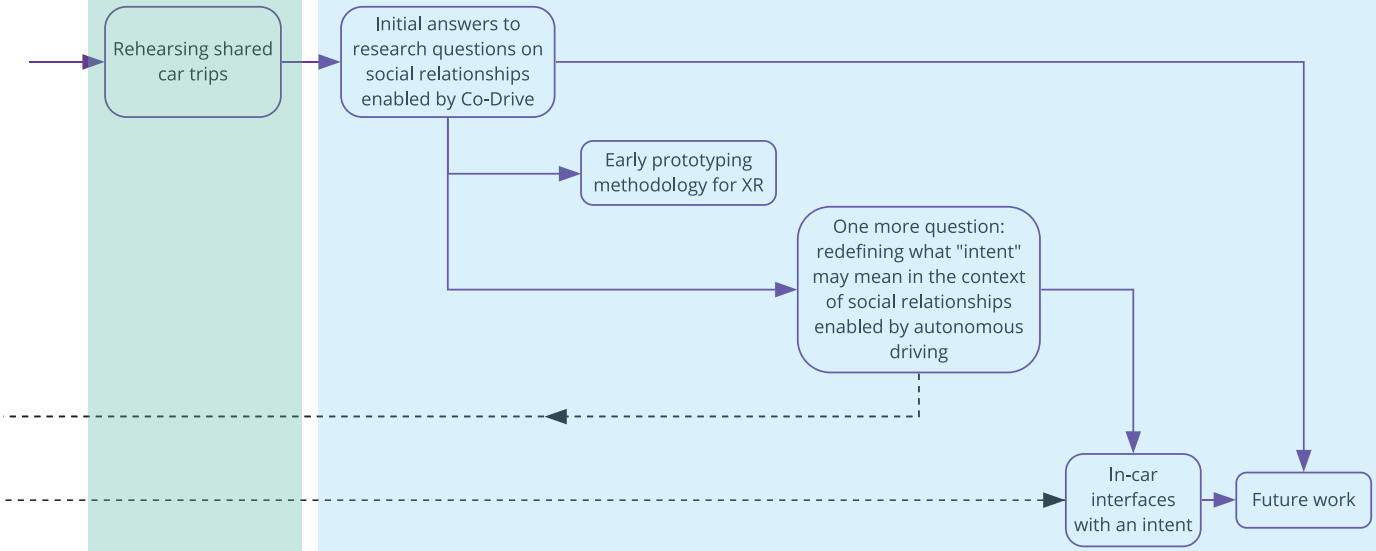
List of Abbreviations

AR	Augmented reality
AV	Autonomous vehicle
eHMI	External human-machine interfaces
MR	Mixed reality
TAC	Thoughtful Autonomous Cars
VR	Virtual reality
XR	Extended reality


Chapt.1
Chapt.2
Chapt.3
Chapt.4
Chapt.5
Thoughtful autonomous cars TAC
CARS WITH AN INTENT
Co-Drive
Designing an early prototyping methodology for an XR experience
Placing a Co-Drive Stop
Booking a Co-Drive trip
Exploration around Trotro Buses in Ghana
Experimental study
Driven by curiosity, I frame a design intuition into a research question.
After exploring 2 early design concepts, I select one,- Co-Drive, to be the focus of my thesis.
By collocating Co-Drive concept in the Extended Reality (XR) domain, I contribute to the existing research with an early prototyping methodology.
I recruit driver participants and they place Co-Drive stops around the world.
Beyond private drivers, I also conduct the experiment with traditional bus drivers in Ghana to address passenger participants feedback, as collected in the early exploration.
I recruit passenger participants, they create their avatar and book a Co-Drive trip by using the virtual Atlas of Co-Drive Stops.

Chapt.6

Chapt.7



Experimental study

I pair driver and passenger participants to run shared car trips in 3 cities in Italy. The car-pod prototype is deployed. Passengers test 3 modalities to join the trip: screen, projection and VR headset.

I draw initial conclusions on how Co-Drive can enable intergenerational relationships and a new social assemblage to emerge, as well as to tackle the sense of loneliness in senior adults.

I highlight the early prototyping strategy for XR experiences as a contribution for the research domain as it lowers the technical prototyping barriers and avoids preventive rejection in new users of AR/VR.

I reflect back on the meaning of "intent" in term of social intent of autonomous cars, especially applied to the Co-Drive concept.

I suggest that the social "intent" unfolds through the teledriving capability and the in-car interfaces that the car may be provided with to support social experiences such as Co-Drive.

Chapter 1

Introduction

In a near future autonomous cars will likely populate the urban environment together with traditional cars and other road users. While they will actually consist of urban- scale robots immersed in a socio-technical context, so far autonomous cars have been almost exclusively looked at from the perspective of safety and functionality and they have not been designed towards acting as social urban beings. "Cars with an Intent" is a design- research driven PhD project which envisions cars beyond their core objectives of functionality and safety, and explores how positive and enriching car-to-human and human-to-human relationships can be prompted by embedding social intentions and behaviours in the car.

1.1 From design intuitions towards research questions

My research departs from the idea that autonomous cars should be looked at as a particular kind of social robot [1], due to 1) their physical scale, 2) the socio- technical, urban context they will inhabit, 3) the artificial intelligence they are provided with. My intuition is that for a positive and enriching relationship with humans, autonomous cars inhabiting our neighborhoods should be approached beyond purely their driving functionality and safety towards supporting the emergence of new kind of social actions. In the recent participatory design initiative by Gehl Architects and Ford Smart Mobility, called "Living street of to-

morrow" [2], they have listed as a design principle the following (citing from the website): " [...] our mobility devices should be as emotive as we are. Good vehicles are as empathetic, expressive and considerate as people are. They respect human attention spans and cater to human desire for empathy and connection. They facilitate real human connection through people watching and opportunities for interaction."

Recent research about the trolley dilemma also reported that the biggest roadblock of autonomous cars adoption may be not technical at all, but psychological: at the moment people say they would fear riding in autonomous cars because they wouldn't trust them [3]. Trust is characterized by the willingness to yield vulnerability to another entity and it is critical that people can comfortably predict and understand the behaviour of the other entity, being it for example an autonomous car. A strategy could be to design the autonomous cars interfaces so that users could have some transparency on their intentions and decision making, but not too much to overwhelm people and induce anxiety [4] [5]. A consistent amount of work has been recently conducted on the topic of trust calibration in autonomous driving, which describes the congruence between an individual's trust in automated systems and its abilities [6]. In particular, Locken et al. suggested the design of ambient light display inside an autonomous car [7] [8], while Wintersberger et al. introduced augmented reality interfaces [9] to convey the state of the car and its short plan. Zihsler et al. [10] prototyped a physical avatar which used social cues and anthropomorphism to translate the car's state and intentions into human behaviours, so that car occupants could easily interpret them. That said, I think that allowing multiple ways for cars and humans to interact in the urban environment that are not strictly functional to driving and safety could also support building trust since people could elaborate mental models of artificial cars behaviours as enacted in multiple situations and contexts. It would be like attending to the behaviour of a social being and collecting evidences of its attitude in neutral situations, when one's focus is neither on probing nor on judging.

Drawing from my initial intuition of looking at autonomous cars as social urban beings beyond driving and safety functionalities, I crafted an initial design challenge as a starting point of my design exploration:

How might humans bond with and through autonomous cars beyond safety and pure driving circumstances by taking advantages of the perceptual and decision making abilities of such vehicles of the future?

A foggy, initial design challenge is far from being a PhD research question, but inspirational enough to give rise to a couple of design concepts to start from. Infact, "Cars with an Intent" departs from two different design concepts: *Thoughtful Autonomous Cars* and *Co-Drive*, which focus respectively onto human-to-car and human-to-human relationships enabled by autonomous cars in the future.

Thoughtful Autonomous Cars

This concept envisions car-to-human relationships in which cars express their friendly attitude and a sort of social embedded intentionality to people in the streets by means of projections onto and outside of the car. The concept unfolds in several exemplary scenarios, which will be further described in Chapter 2. For example, thanks to their artificial viewing capabilities, driverless cars will be able to spot amazing views that are not accessible to humans, store them as pictures and let passing-by pedestrians enjoy them as projections. Cars storing a memory could show an aura on the car roof when parked and people, by knocking on the car windows, could then unlock it and get it shown as a projection.

Co-Drive

This concept envisions human-to-human relationships enabled by a highly automated car. Co-Drive is a new way of traveling and socializing by cars between a driver and a remote

passenger using VR at home. In this concept, the autonomous car will be able to host a remote passenger inside the vehicle through a digital or robotic embodiment, as well as be driven from home by the remote passenger. The social intention of the cars could be conveyed by in-car interfaces, such as the interface for the remote passenger embodiment.

1.2 What and whose intent?

Research conducted on autonomous cars have been currently focusing on the communication of the car's intent both to the passengers inside the car, as already described in the previous section, and to other road users. For "intentions" it is meant the short term plan that the car will perform in an autonomous way, such as slowing down, breaking to let a pedestrian cross, following a particular trajectory, and so on. The reasons why the intention of the car could get communicated to the car occupants are to help understand the decisions of the automation and make it easier to assess the current driving situation when needed, for example in case of a take-over request [7] [8] [9] [10] . Similarly, the reasons to communicate the car intention to pedestrians, cyclists and other drivers are to facilitate co-existence on the roads and replace social signals which have helped roadway negotiations between humans so far, as in the case of the visual Intention Indicator concept by Nissan [11]. Car drivers and other road users have been communicating their intention largely through movement, eye contact and body gestures and researchers on autonomous cars are currently facing the challenge of how to substitute and translate such a way of communication to autonomous vehicles. In this research, intent is meant beyond driving and safety functionality towards the emergence of social relationships. I try to probe if automation in cars can also include social intentions and to do so I will explore new emerging social relationships between autonomous cars and humans, as well as between humans through autonomous cars. Therefore, I pose

"What and whose intent?" as an open question to which I will come back at the end of the thesis.

1.3 The structure of the thesis

This research is structured in 7 chapters, including this one. As a guide to the organization of this work:

Chapter 2 describes the 2 initial design concepts that I respectively co-created and experience-prototyped before narrowing down to the one concept which will be the focus of the PhD research. I will define the PhD research questions around it.

Chapter 3 presents the methodology I came up with to prototype the Co-Drive concept, which is framed as an XR experience.

Chapters 4, 5, 6 delve into the 3 prototyping interventions which allowed drivers and remote passengers to enact the Co-Drive experience in its main interactions. Results of the interventions are presented and discussed in each chapter.

Chapter 7 summarizes the main outcomes of the thesis, as well its limitations, and opens up to a future continuation of the research.

Chapter 2

Which way to bond

In Chapter 1, I have framed a design intuition into a research question, driven by curiosity: How might humans bond with and through autonomous cars beyond safety and pure driving circumstances by taking advantages of the perceptual and decision making abilities of such vehicles of the future? In Chapter 2, after exploring 2 early design concepts, I will select one, Co-Drive, to be the focus of my thesis as it deals with the so-far unexplored emerging social relationships between people which can be enabled by autonomous driving.

Cars with an Intent research departs from two different early design concepts: Thoughtful Autonomous Cars and Co-Drive. The first one explores how to bond with an autonomous car as a human, the latter one how to bond through an autonomous car between humans. Much research has been recently done to explore the social aspects of autonomous vehicles and how they would shape the interactions that are part of traffic when they will populate and be integrated in the urban environment. From the lens of the social sciences, Vinkhhuyzen and Cefkin [11] highlight that as traffic is a particular form of public social life and each act involves the interpretation of cultural signs and signals, then even those aspects of mobility which at first seem purely technical (accelerating, slowing down, etc.) need to account for their social skills. Their research into ”socially acceptable cars” argues that it is extremely likely to occur that the ”social” gets lost in the process of abstracting the users be-

haviours into autonomous vehicles' engineering, such as the processes of negotiation between road users. In order to solve this, they come up with the idea of the Intention Indicator, to allow negotiation between drivers, pedestrians and autonomous vehicles by representing the car's intentions of movement through a light strip as external interface. Many other researchers have been exploring the potentially similar approaches based on eHMIs (external human-machine interfaces) as a way to support the interactions between autonomous vehicles and other road users [12], up to conceptualizing shape-changing interfaces [13].

From a more methodological perspective, Stromberg et al. [14] focus their attention on which design techniques could be effective in the design of future social experiences with and within autonomous vehicles. Their contribution open up the design space to future social interactions happening not only between the road users and the autonomous cars, but also between people sharing a trip in the same vehicle and between the new-driver/user and the autonomous car. The methodological approach they devise consists of a different set of design methods for each of the outlined social experiences they focus on. The methods range from Wizard-of-Oz to peer-to-peer interviews, as each is meant to unfold and reveal different interactions and social aspects with autonomous vehicles. As the car gains increasing agency, the design of such autonomous vehicle needs to take into account both the existing social contexts in which cars have been acting so far and in which social interactions have been grounded, as well as needing to probe into the possible futures and envision which new interactions and contexts of use may emerge from such technological possibilities. New technologies affect the environment they are introduced into, bringing intended and unintended consequences [15] which exploratory design methods could help anticipate and untangle.

In this chapter, the two initial concepts of the research, Thoughtful Autonomous Cars and Co-Drive, are first introduced through their scenarios and then, the design methods which allowed probing with users and stakeholders are described. The chapter ends up revealing the research direction which was eventually selected as the core of the PhD project and the

reasons that brought to that choice are argumented.

2.1 Thoughtful Autonomous Cars

This concept envisions car-to-human relationships in which cars express their social attitude as some sort of embedded intentionality and behaviour towards people on the streets by means of projections onto and outside of the car. The concept unfolds in the following several scenarios, pushing beyond pure driving and safety functionalities.

The Empathic Cars

Autonomous cars would have the ability to sense the trust of pedestrians and behave accordingly. Sidewalks and streets would be rethought. Cars would show their behavioural attunement to pedestrian's trust through a projected aura that will show the distance which the car will keep from the pedestrian, attuned to the specific trust towards autonomous cars of that specific person (Fig. 2.1). This behaviour is meant towards establishing a personal relationship with pedestrian which could evolve through time.

The Collaborative Cars

People would enact a particular movement/choreography to cross the streets. Autonomous cars would have the ability to interpret the choreography and coordinate among themselves to let the pedestrian cross. The cars would project in front of them the zebra crossing if they intend to let the pedestrian cross (Fig. 2.2).

The Aura on the Roof

Autonomous cars would have the ability to spot amazing views thanks to the sightseeing abilities granted by sensors. The car will store pictures of those views and, when parked,

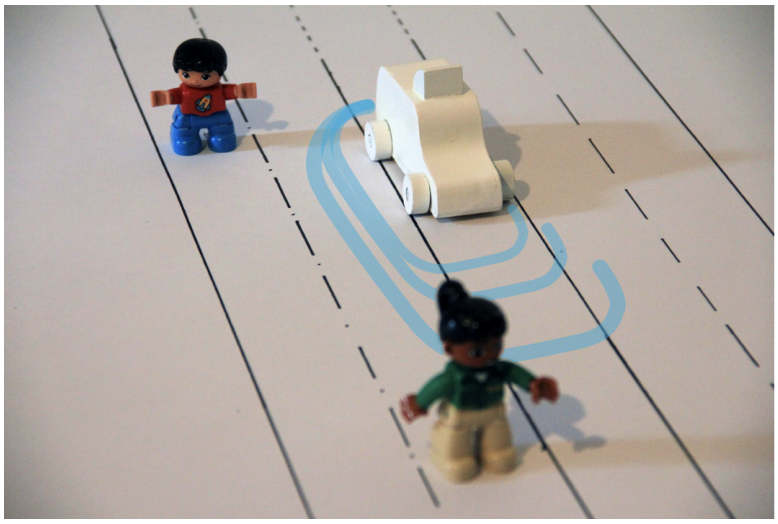


Figure 2.1: The Empathic Cars scenario with the car projecting the aura of trust.

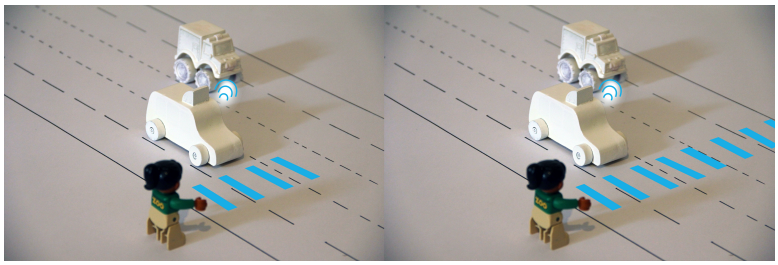


Figure 2.2: The Collaborative Cars scenario with the cars jointly projecting zebra crossing.

will project a halo on its roof to signal that a one-of -a-kind picture can be seen. A person can knock on the car and ask the car to display the picture onto its windows or windscreen. The display of such a picture is as rare as a halo, happening just one time (Fig. 2.3).

The Car with the Eye

Autonomous cars would have an eye that pedestrian or other drivers could look at to negotiate transitions on the street. The car eye will turn to the pedestrian/other driver and blink to grant the crossing (Fig. 2.4). If the pedestrian/other driver thanks the car, the pupil turns into a heart.

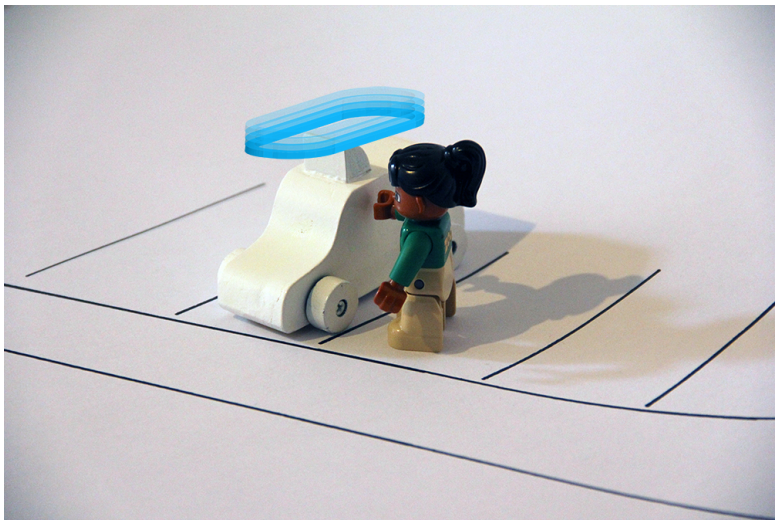


Figure 2.3: The Aura on the Roof.

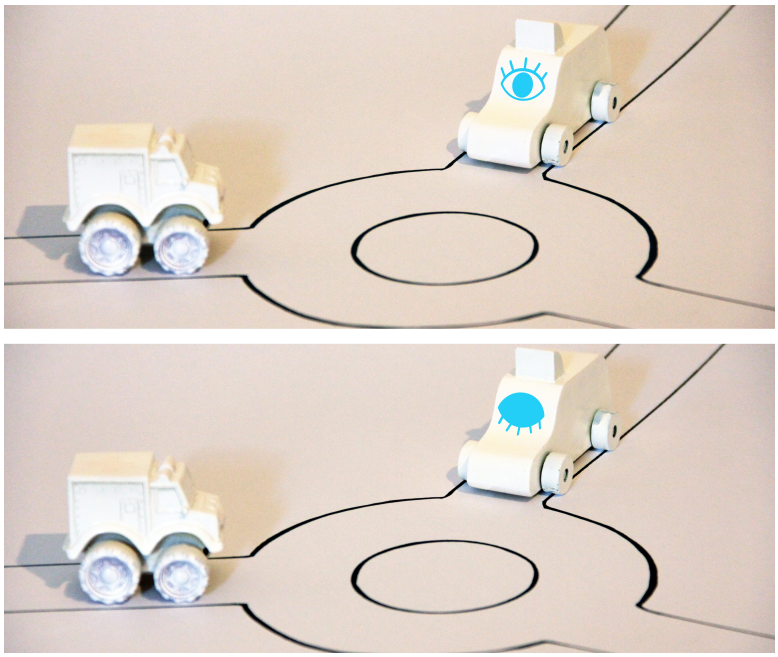


Figure 2.4: The Car with the Eye blinking to another car to indicate to go first.

2.2 Co-Drive

This concept envisions human-to-human relationships enabled by autonomous driving and suggests a new service for traveling and socializing by car between a driver of a semi- autonomous car and a remote passenger connected via virtual reality from home. A semi-autonomous car will be able to host a remote passenger inside the car as a hologram (by the way, during the research I have been exploring voice-only in-car presence of the passenger and robotic embodiment) and real time communication between the driver and the remote passenger will be enabled. At the beginning, prospective remote passengers can select a location from where to start their Co-Drive trip from among the many stops around the world which have been featured in the Co-Drive Atlas and place their avatar there to book their trip. A Co-Drive stop is the physical location where a Co-Drive trip can start from, blending the real and virtual into an extended reality experience for the driver as well as for the remote passenger. A driver passing nearby the stop where an avatar has been placed would spot such an avatar as an AR visualization on the car windshield.

Figure 2.5: On the left, the person records his/her hologram at home; in the center, the person is picked up by a driver and gets notified through the TV; on the right, the person turns into a remote passenger on the car by wearing a VR headset (in the picture, paper props are used as placeholders for tech devices), even with the option to take-over if desired.

S/he and can decide to pull over, start engaging remotely with the person embodied in the avatar and eventually board her/him in the car as a remote passenger for a shared trip

together. They could both converse "live" during the trip, while the remote passenger could also enjoy the view as if sitting on the passenger seat by wearing a VR headset (Fig. 2.5). A video scenario has been mocked-up to show the main interactions between the driver and the remote passengers [16].

The Co-Drive concept builds on the premises that the convergence of automated driving and telepresence technologies could provide a new social context for personal interactions to emerge, that are neither dependent on any earlier established relationships nor based on age affinities. For instances, as remote passengers could likely be older adults and drivers younger ones, the Co-Drive concept could foster intergenerational encounters that wouldn't naturally occur in our environment, at least in western cultures. Anyway, we could imagine that many people from a wide age-range would be interested in driving tours of remote locations and similarly, it may well be older people that have time on their hands doing the driving.

2.3 Probing initial concepts

2.3.1 Thoughtful Autonomous Cars workshop

Thoughtful Autonomous Cars concept has been co-created during a workshop with researchers and stakeholders at Fraunhofer AICOS in Porto (Portugal), which hosted the session. 9 participants were recruited among Fraunhofer's clients network, who worked in the R&D department of car companies/ car equipment manufacturers and software houses involved in driving projects.

Unlocking Autonomous Cars Sensitivity

The workshop was entitled "Unlocking Autonomous Cars Sensitivity". It consisted of a half day co-creation session which involved participants in creative, hands- on activities around the technologies on board autonomous cars and all the potential capabilities that remain unexpressed and unexploited. The recruited participants ranged from engineers, designers, human factor specialists, software developers, all sharing a deep understanding of the technologies inside the car of the future. The aim of the workshop was to appropriate (and contaminate) the technological knowledge from the participants and to brainstorm possible new uses of such technologies beyond pure driving and safety functionalities, towards a more social application.

Activities

The workshop unfolded in 3 different activities.

The first one was a warm-up excise and prompted participants to focus on their knowledge of autonomous vehicles (AVs) capabilities: which capabilities are unexploited and which ones would they suggest for the future AVs that would surprise them? Participants were provided templates to fill individually, stick them on a collective board on the wall and share back to the group (Fig. 2.6))

In the second activity participants were asked to imagine a "sensitive car" and to sketch interactions between that car and other urban actors, such as pedestrians, animals, other cars, etc. They were provided with a tool made from wooden tiles that could be put together, which enabled them to physically bind the "sensitive car" with the other possible actors through elastic bands. Participants had to label the interactions they envisioned between the two actors and attach them to the relative elastic band. I decided to use a wall board to mirror the work done with the tiles, which allowed to expand the work space. Longer

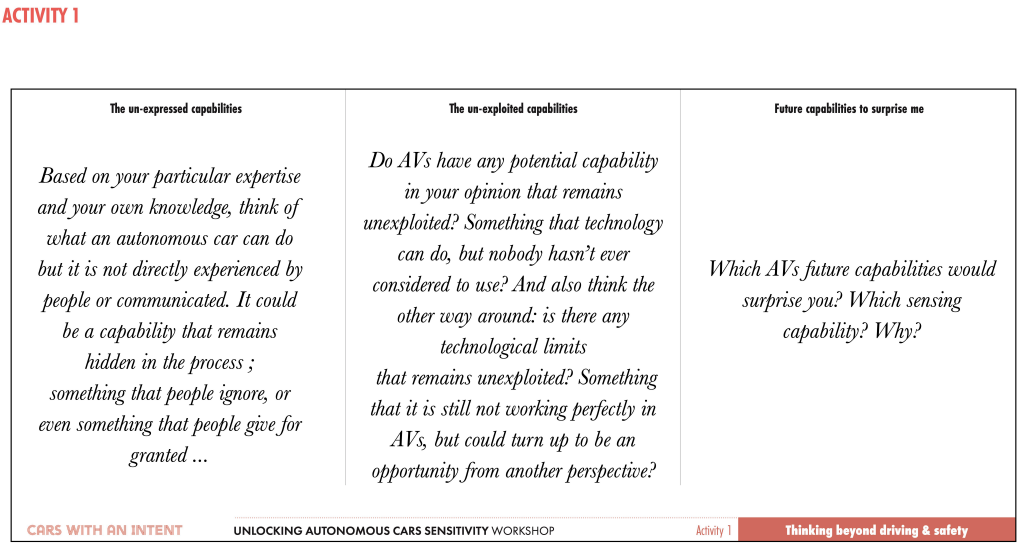


Figure 2.6: The wall board of Activity 1.

descriptions of the envisioned interactions were written on paper cards and attached to the wall board, so to avoid the tiles getting too packed (Fig. 2.7).

The third activity required participants to divide into 2 groups and to select one favourite interaction between a ”sensitive car” and other urban actor from the ones created in the previous activity. Then, they had to develop a complete scenario following the scheme provided (Fig. 2.8))

Results

Participants came up with 2 different concepts. One was about a ”sensitive car” interacting with a blind passenger. According to the concept, the car would be a driverless car and it will take care of explaining the surroundings and the traffic situation verbally to the passenger (Fig. 2.9). The other was about a ”sensitive car” matching its ”personality” with the passenger mood. The car will express itself and its matching mood through interior

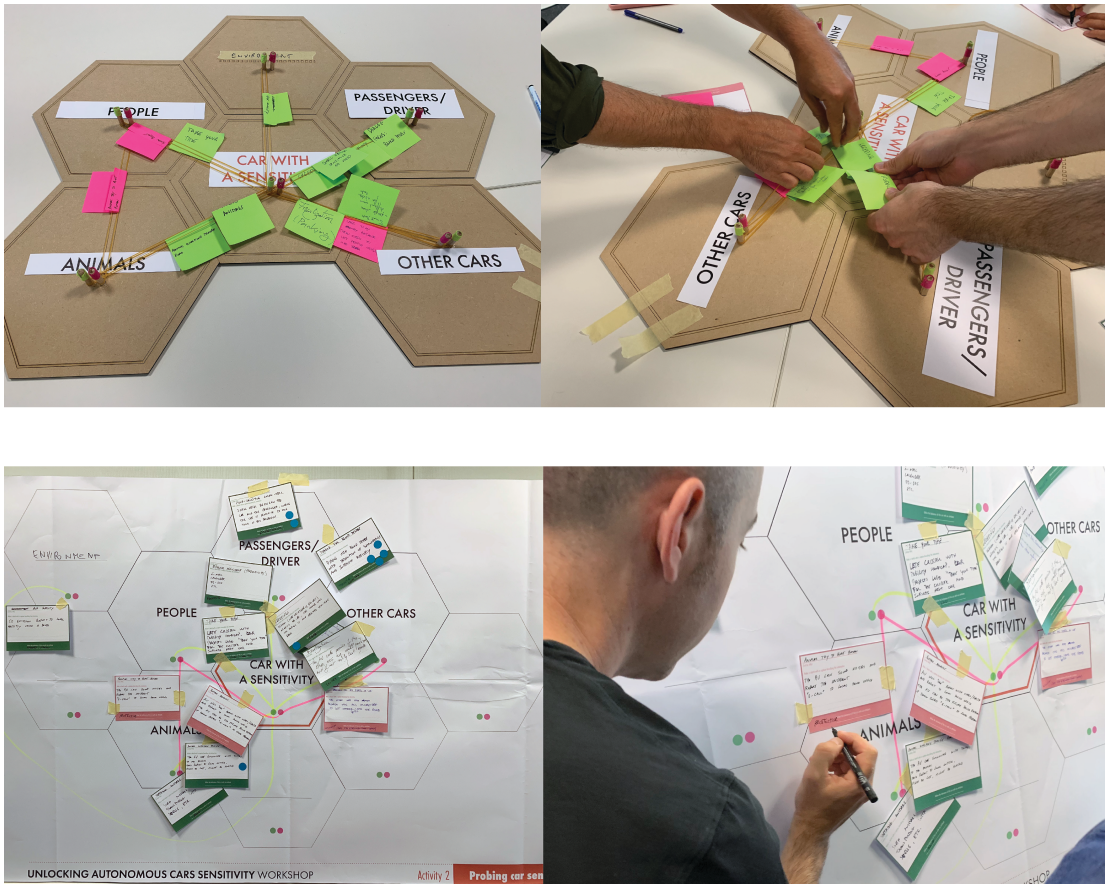


Figure 2.7: Sketching relationships between the "sensitive car" and other urban actors in Activity 2.

features (such as ambient lightening) as well as through small talks which it would initiate to bond with the passenger.

2.3.2 Co-Drive experience prototype

In the first phase, the representation of Co-Drive into a prototype for participants to experience would face a series of technological implementation issues, as well as the risk of raising early rejection in elderly participants due to their unfamiliarity with the concept of auto-

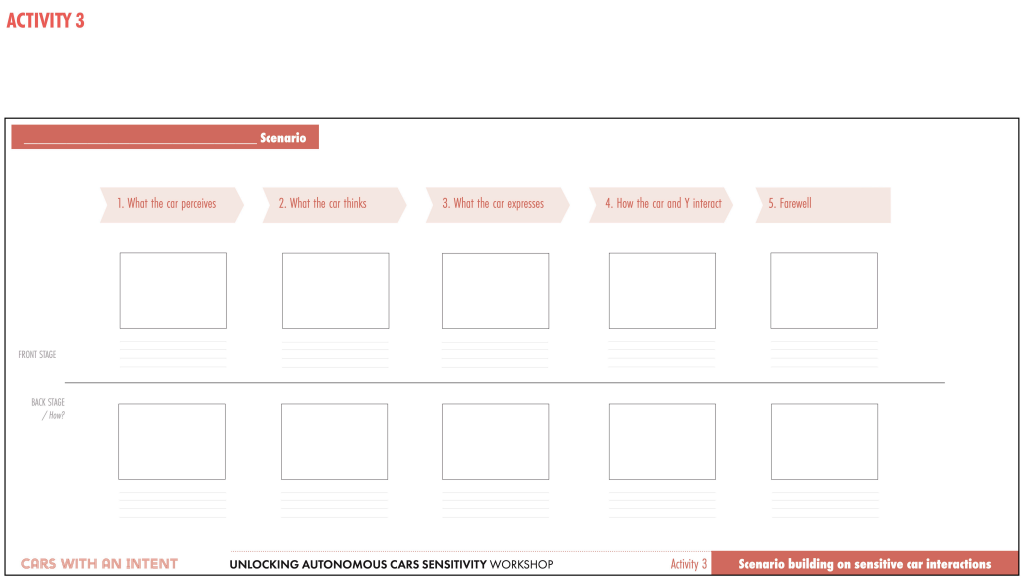


Figure 2.8: The scheme for the scenario building in Activity 3.

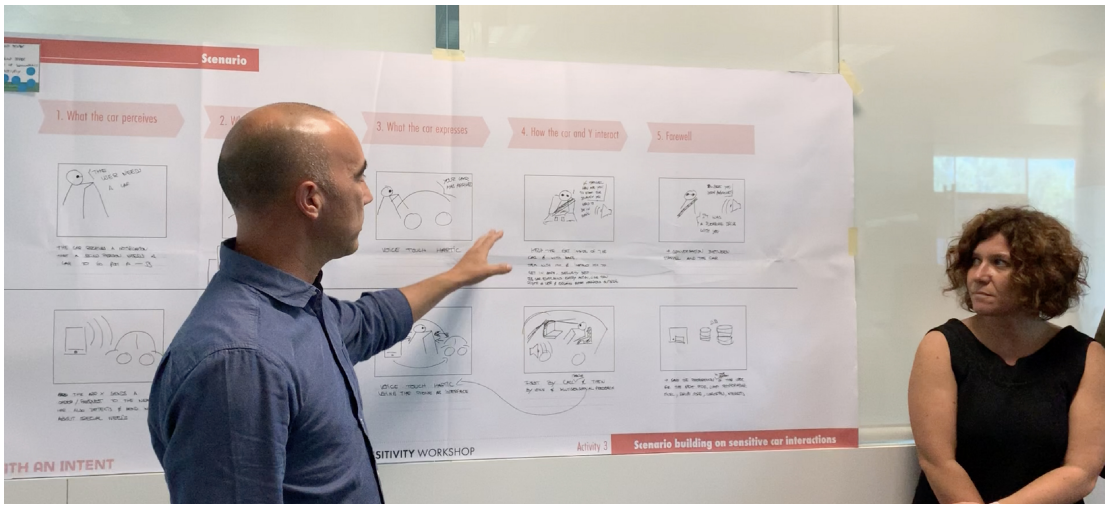


Figure 2.9: A group presenting the scenario of the "sensitive car" interacting with the blind passenger in Activity 3.

mated cars and with VR devices. Such constraints forced us to focus the prototyping effort onto the basic, yet fundamental social experience enabled by the concept, postponing any

technological development and interface design to a future stage. Experience prototyping [17] seemed to be the right approach to emphasize the experiential aspects of the Co-Drive concept and to explore future development of the idea through people contextual insights. Experience prototyping differs from other prototyping techniques because it requires an active participation of people to provide a truly subjective experience. It consists of a design intervention into the actual context of people, which enables participants to rehearse a possible future [18] and make sense of it from the own subjective perspective and values.

Experiment outline

Six women and one man aged from 72 to 88 were recruited from the day care Cooperativa Sociale Nuova Socialita' in Rome, Italy. Preparatory interviews by myself were conducted with the participants the days before. Each participant was individually met at home, and a semi-structured interview was unraveled to probe their own traveling routines and what traveling means to each of them. At the end of the interview, each one was invited to join an experiment of a new kind of travel. If they wanted to join, they would have been picked up by the social service and taken to the day care structure where the experiment would have taken place. The experiment, which consisted of the Co-Drive experience prototyping session, lasted 40 minutes plus 30 minutes of collective discussion soon after. Videos and pictures were taken during the session.

Set-up

Experience prototyping can free the design process from early technology development and rely on a "quick and dirty" approach. For the sake of the project discussed in this paper, a basic in-car broadcasting system would have allowed the driver to show its journey to the remote passenger, and an immersive-enough display [19] would have conveyed the view from the car in motion to the remote passenger. Audio live communication between the two per-

sons would have also been required. As a broadcasting system, the driver was equipped with a smartphone with the Periscope app running on it [20] and with a second mobile phone just for audio communication. When deciding for the technical setup for the passenger, different considerations have been taken into account, such as: 1) the familiarity of the remote passengers with any possible immersive technology and 2) their traveling habits. Concerning the first point, participants for this experience prototyping were elderly people (70 years or older) and had never used a VR headset before. Scaring participants or polarizing their attention on the "VR goggles" technology was out of scope, so an alternative solution needed to be searched. Regarding the second point, that group of elderly represent a collective that attend a day care and have no occasions to travel outside the bus trips organized by the social service for the entire group. They are a community of practice in that sense [21]. Grounding the experiment to their actual travel practice would have bridged the Co-Drive future vision to the participants' every day context, thus helping them to appropriate the idea and envision possible meaningful interactions for the future. For the reasons described above, the experience prototype was designed so that the elderly participants travelled as a group, sitting in the social center leisure room as if traveling on a bus and watching the car view from a big projection on the wall in front of them, as if it was a bus windshield. The driver and the remote passengers could speak to each other during the trip thanks to a (hidden) speakerphone communication (Fig. 2.10). A video of the whole session was edited and published online [22].

Results

As a result of the experience prototyping session, a series of actionable insights were synthesized onto which to ground the future iteration of the Co-Drive concept.

On travel as Older Adults

- As participants aged, they generally have not so big expectations of enjoying them-

Figure 2.10: On the left, the driver on the wall projection; in the center, the remote passengers as sitting on a bus; on the right, a view from the trip .

selves through travel because they get used to coming back to the same locations for convenience and meet the same people. They acknowledge that travel can be a great way to make new friends, even if there is no opportunity for them to meet younger people.

- As elderly, they are used to traveling all together by bus on the day-care trips. They enjoy talking, singing, and eating on the bus.
- They would like the bus to travel through places they couldn't reach walking due to their reduced mobility, such as historical town centres.
- New meetings between young and old are difficult to occur because they have different lives. Anyway you can trigger them by starting from something they both enjoy.
- They would love to have more car trips, just to sight-see new places from the window. Stops would be short just for a coffee or to see a detail during the travel (e.g., flowers on the way or a panoramic view).

On being Co-Drive Remote Passengers

- It is key to allow a near to zero-latency communication when the driver and passengers speak.
- Passengers were nicely surprised to discover that the driver was "alive" and spending

his time bringing them around as a local.

- Remote passengers were hesitant to start the conversation with the driver. Maybe an introduction by him on the reason of his trip would be ice-breaking. They would have required to be prompted to talk to him more.
- Some passengers would have liked to stop and see things closer or even to suggest a direction to go.
- If the experience was to be repeated in the future, some passengers would prefer to co-drive again as a group, like they did in the experiment, but few would like to try it just with the driver.
- They expressed very clear destination wishes for the next co-drives and usually were far away continents where they had never been. They would like the driver to be a local and get to know a bit of the culture.
- As they could see the driver, they would have liked the driver to see them. They had no issue in being broadcasted as well.

2.4 Narrowing down: Co-Drive concept as my research topic

After the initial exploration of the two concepts, Thoughtful Autonomous Cars and Co-Drive, several reflections were drawn to inform which direction to focus the research onto. It needs to be acknowledged that a growing body of research can be found in which the focus is on autonomous cars and their relationships with humans, while the domain of human-to-human relationships through such agentive cars remains uncharted. Although the workshop on TAC produced interesting outputs, most of them were aligned with streamline research topics of

intent communication and trust between autonomous vehicle and other road users. What instead struck me was the sociality dimension that powerfully emerged from the first experience prototyping of the Co-Drive concept. Even though the early prototype car equipment was based on a very limited and mocked-up technology, the experience observed was that of an encounter enacted by the participants, both driver and remote passengers, through the car. Attending to the empirical evidence that sociality is not much something as a designed property of a *machine* [23], as intelligent if could be, but rather an evolving relationship enabled by such a *machine*, I wonder which designed intent could then animate the *intelligent machine* so to foster people encounters and social behaviours among them. How to support human-to-human relationships through autonomous cars quickly surged as the driving motivation of my research and the Co-Drive concept was selected as the core concept to focus my project on.

2.4.1 Co-Drive research questions

As remote passengers will likely be older adults and drivers younger ones, the aim of the research is to understand how the "Co-Drive" concept could support intergenerational encounters and relationships and reduce the sense of loneliness in senior adults. It is well known that intergenerational relationships are mutually beneficial for the different aged people involved and a growing number of programs have been experimented to enable such encounters and nurture the on-going relationships [24]. In the framework built by the Stanford Center on Longevity [25], a degree of intentionality fostering intergenerational programs (meant as "reasons why the participants should meet") is highly recommended because it would favour the match-making between the people involved, help forming meaningful relationships and, eventually, it would be conducive to bringing mutual benefit to both persons. On the other hand, coming from the angle of environmental design, Kaplan et al. [24] and Danely [26] in-

troduce the importance to enable serendipity and spontaneity in intergenerational encounters and encourage the design of spaces for flexibility and users' modifications so to complement intentional planning. The novelty brought about by the Co-Drive concept is that it would enable casual encounters between people of different ages, without the need of having any reasoned motivation for that encounter. This openness doesn't mean that the reasons of the encounters are not important for the sake of the project, on the contrary I expect that each participant, who voluntarily joins the car, would bring the very own reasons to each car-trip encounter. Collecting those subjective reasons and the meaning participants attach to the trips would be one of the research interests of the project. Concerning the car as a peculiar environment and social setting, many studies have described how driving is connected to sociality and how social interactions between the driver and passengers are interlaced with the process of driving. Laurier and Dant [27] consider driving together a form of social group moving and of being together. They studied how the talks happen in the car, from topic generation, sequencing and closing. With the advent of autonomous cars, they wonder how the social interactions within the car will be transformed. Dant and Martin [28] highlight the degree of intimacy that could be reached among the driver and the passengers when sharing a car trip, and how through a trip together one can get to know someone much more quickly than in other "social context". They also stress the fact that the physical co-presence inside a car allows body movements and gestures to cue conversation, and in this context any occasional glance exchanges, while the driver is paying attention to the street, may thereby gain more significance. Dant also introduces the "driver-car assemblage" [29] as a form of social beings that produces a range of social actions. The driver-car assemblage is not a matter of chance mating, but the result of a design process, opening up the discussion on how the collaboration between human beings and material objects contribute to the formation of social life. Moreover, Dant stresses the fact that the car does not simply afford the driver mobility, but it enables a range of humanly embodied actions available only to the

driver-car. What social actions would the new Co-Drive assemblage, driver- autonomous car- remote passengers, produce? Which form of social group and togetherness such remote travels would let emerge? How the car environment would enhance and transform the sense of togetherness along a remote car trip? In the following part of the thesis, I will unfold the study conducted on the Co-Drive concept trying to address those questions through means of design research and prototyping.

Since the Covid-19 pandemics struck in Italy during the development of the project, tackling senior adults isolation became even more significant for the study and I paid particular attention to understand how Co-Drive could support seniors to feel connected and less lonely during the Italian lockdown. To conclude, as a secondary research question for my project, I aim to understand how the "Co-Drive" service could enable an ageism-free approach towards senior adults through the use of digital and/or robotic embodiment of remote passengers. Burema [30] already addresses the representations of older adults in human-robot interactions and how ageism is perpetuated when older adults are depicted as dependent, fragile and vulnerable people. As the Co-Drive service first engages seniors in building their avatars and then envisions the seniors' embodiment in the car through some sort of advanced interface, would the hosting drivers perceive any difference in their approach and behaviours towards the senior, remote passenger? Would Co-Drive act as a counter-narrative to help fighting a biased, stereotyped and problematic understandings of older adults?

Chapter 3

Prototyping Co-Drive

In Chapter 2, after exploring two early design concepts, I have selected one, Co-Drive, to be the focus of my thesis and I have narrowed down my research questions specifically around that design concept: i) How can Co-Drive support intergenerational encounters and relationships? ii) Which form of social group and togetherness would the Co-Drive trips let emerge? iii) How can Co-Drive reduce the sense of loneliness in senior adults? In Chapter 3, I will collocate Co-Drive concept in the Extended Reality (XR) domain and I will outline an early prototyping methodology which will be implemented later on in the rest of the project.

The Co-Drive experience is grounded on the situated social experience of a shared car trip [31] [32], yet it expands such an experience by enabling it between two persons who are not physically close to each other by means of mixed reality (MR) technologies [33]. Therefore, the Co-Drive concept could be considered as a social extended reality (XR) experience. XR combines AR and VR technology to deliver a unified experience blurring the reality and the virtuality which is neither felt completely real nor completely virtual by the participants who will engage with it. The way XR is framed in my research builds on the concept of MR-mixed reality, as defined by Milgram and Kishino [33], and expands it beyond its technological perspective towards a more ecological and cultural approach.

3.1 Co-Drive as an XR experience

Milgram and Kishino identified different hybrid environments which present a mixture of real and virtual world and organized them along a ”virtuality continuum”, going from the pure real to the pure virtual environment. Examples of mixed realities are augmented reality (AR), where the real world is augmented with virtual features, and augmented virtuality (VR), where the virtual world is augmented with real features. When they firstly introduced the concept of the ”virtuality continuum”, they were focusing on the technological aspect, looking at discrete ”display situations” in an attempt of building a taxonomy for existing hybrid displays. Likewise, Hirose et al. suggested that mixed reality interactions usually occupy a specific point in the continuum instead of spreading over it [34], thus involving that the user interacts with a single interface for the fruition of the experience. Anyway, as the technology and connectivity supporting hybrid experiences continues to develop towards better real-time communication and high-fidelity representation, the perspective on MR applications has been embracing a much more socially-oriented horizon than ever before. Billinghurst at al. acknowledged that as mixed realities experiences permeate human and social activities, discrete MR interfaces could not be enough to capture the complexity of people’s interactions. Users often may prefer to be able to easily switch between interface types for a more natural fruition of the experience, introducing what they called ”transitional interfaces” [35] [36]. An ecological-cultural approach towards XR experiences thus implies to shift the attention from a single MR interaction towards a plurality of interactions happening along the continuum line and to take account of the possible collectives of interactive users in real world settings. In a recent revisitation of the virtuality continuum, Skarbez et al. also accounted for the discontinuity of the reality-virtuality continuum and reflected on how broader contemporary XR experiences can be if compared to what believed before [37]. As the technical development of XR applications relies on the time consuming work of highly

skilled professionals [38], designers urge to come up with new ways for rapid prototyping XR experiences and quickly perform iterations on the concepts prior to any expensive endeavour. Billinghurst et al. have already been working in the field of XR rapid prototyping for non technical people, suggesting paper-based XR design templates and easy-to-use digital authoring tools [39] to overcome the programming barriers that are usually faced by people with no engineering background. In the following sections, I illustrate the early-stage prototyping strategy for Co-Drive, which departs from deconstructing the concept into its main interactions and them mapping them out onto Milgram and Kishino's virtuality continuum.

3.2 Background

3.2.1 Prototyping tools for XR experiences

As AR/VR technologies have tremendously developed in the recent years, so the affordances and interactions enabled by them have increased, making it difficult for designers with no programming skills to prototype immersive XR experiences [40]. In this section we try to give an overview of the available prototyping tools, from the more sophisticated to the easier to non programmers, and we highlight the value of such existing prototyping strategies. Prototyping tools for AR/VR share the goals of providing a way to build interactive applications for co-creation or testing purposes with users. Speicher al. [41] have been framing a prototyping landscape for AR/VR and grouped the available tools into three main categories: physical, digital, and physical-digital prototyping tools. The difference among the categories is based on the entry barrier for creators, as well as the fidelity of the interactions that can be reached, since both the entry barrier and fidelity are lower in the physical prototyping and then increases in the digital one. Physical prototyping encompasses paper dioramas and

tools such as miniStudio [42], C-Space [43], ARcadia [44], and StoryMakAR [45]. Dioramas have been just used as stages for storytelling with no interactive capability, (they might get activated through means of digital content, as we will see in the physical-digital category later); while the other mentioned tools use physical materials as projection surfaces or for tracking purposes to prototype AR/VR designs. Digital prototyping includes high fidelity tools such as Unity and Unreal, which enable the most realistic outcomes, but do require extensive programming. In this category, we also find medium fidelity tools requiring no programming skills, such as Pronto [46], RealitySketch [47] and XRDirector [48]. They are based on human enactment and physical object movement and how this kind of interactions are bound to a digital counterpart. Pronto is based on human enactment and the use of a physical object (such as the tablet) as a proxy. Digital content will replace the portion of space occupied by the physical placeholder. Pronto is particularly powerful in enabling the quick creation of illustrative videos of an AR experience, though the digital content, meant as the augmented reality layer, appears quite low fidelity and unrealistic. RealitySketch binds a physical object, which can be manipulated in real context by a human, to a responsive graphical visualization that can be previewed through an AR-enabled digital device. XRDirector enables people to sketch AR/VR visualizations collectively by means of a role-based, collaborative enactment in the real space. Digital-physical prototyping, the emerging category between paper-based and programming-required prototyping, include tools such as ProtoAR, 360Proto and 360theater. ProtoAR [49] enables to quickly sketch digital AR overlays from paper drawings or play-dough models. 360Proto [50] requires the use of a particular 360 equirectangular grid template where to draw the scene onto and build a diorama. It does require some training to learn how to sketch on it. As the scene and the overlayered paper cut-outs are hand-drawn, the visual outcome is not realistic. Finally, 360theater [41] elevates lo-fi diorama prototyping, such as 360Proto, to a higher fidelity since it enables digital 3D objects to inahibit the AR/VR scene. 360theater allows the user to

interact with the AR/VR scene and the overlayed digital objects from the mobile device, as the interactive behaviour of the objects are controlled via a Wizard of Oz feature of the system [51]. This tool, though enhancing paper-based diorama prototyping to medium-high fidelity, requires the active involvement of a team of researchers with different roles during the prototyping session.

3.2.2 Reflections

Digital-physical prototyping tools such as 360theater manage to fill a gap between traditional paper prototyping and code-based prototyping, providing designers with a low-entry barrier to test early concepts with a reasonable level of fidelity. For this reason, up to now it may seem the most suitable tool to equip non-programming designers with. Nevertheless, we reflect on several drawbacks that may need to be considered in relation to the specificity of the project when approaching a prototyping session with 360theater. While providing interactivity through Wizard of Oz technique, 360theater needs a particular technical set-up and researchers' orchestration that make it difficult to run experiments in the wild, outside the lab environment. The device interface through which the user experiences the AR/VR scene is mostly a mobile phone or VR headset. While this may not pose any challenge to most of the prototyping session's participants, it indeed may create a barrier if our aim is to prototyping early concepts with people with no previous knowledge or experience with XR technologies, such as older people. We might prefer not to introduce any new device to participants in this early phase, neither to require any active use of such device by participants. In order to focus exclusively on the felt experience, and thus avoiding to compromise participants' feedback by technology inexperience, frustration or even rejection, we may need to enable users to observe the experience in 3rd person view or to postpone the introduction of the device when they would be more familiar with the concept behind the AR/VR expe-

rience. Moreover, even the most-friendly-to-designers tools fail to address the prototyping of XR experiences beyond the single, descrete interactions happening on the device interface. There is a whole ecology of interactions happening over time in the environment, around the user and the device, and even between users, which are not yet considered in the prototyping process and encompass much more than AR overlaying on a screen [52]. As the existing tools manage with different fidelity to test punctual, proxemics interactions happening in a specific moment on a device interface, the next challenge for XR early-stage prototyping will be to broaden the field of the interactions to target, beyond the AR/VR device and towards a prototyping strategy for a continuous and interwoven experience.

3.3 An early-stage methodology for XR prototyping

3.3.1 Mapping the scenario onto the virtuality continuum

As a first step towards the design of an early-stage prototyping strategy, the Co-Drive scenario was mapped out onto Milgram and Kishino's virtuality continuum, producing what we named the "XR experience diagram" (Fig. 3.1).

The continuum line served as the X axis of the diagram, spreading from real environment to virtual reality. The Y axis represents the scenario timeline, and, in the specific case, it is defined by three subsequent phases of the service: T1-Setting up the Co-Drive stop as departure point; T2-The Driver and remote passenger first encounter; T3-The remotely shared car trip. Representative pictures of the different service phases were extracted from the Co-Drive video scenario [53] and placed in the diagram, matching the right spot in the continuum line. When pictures may just be missing at this stage, frames could be left blank as placeholders for a later phase of the design process. Each picture was numbered in a

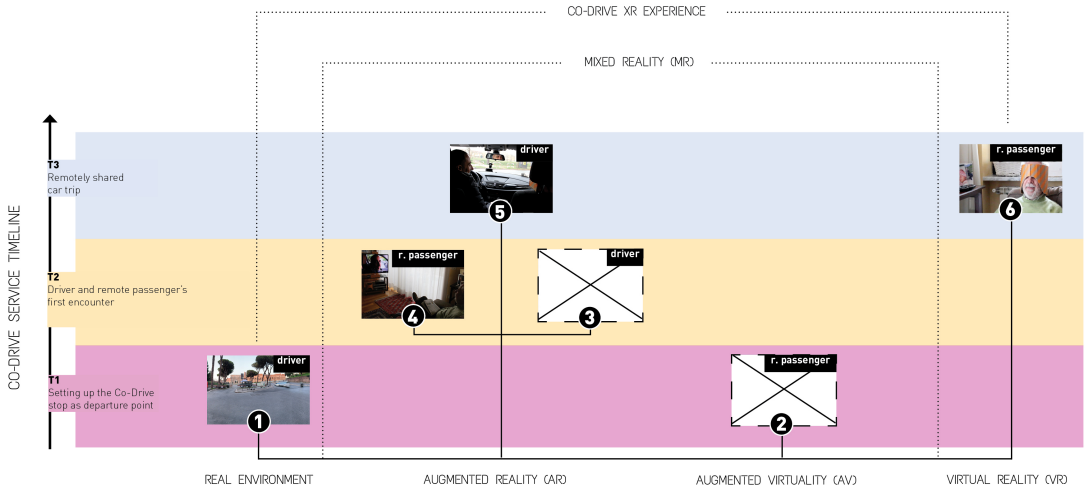


Figure 3.1: The XR experience diagram of Co-Drive

chronological order following the narrative plot of the scenario, as well it was labelled by ”driver” or ”remote passenger” to highlight the interacting user.

Compared to the scenario, the diagram unlocks a more focused perspective on the XR experience, in terms of fluidity among mixed realities spaces, roles and rhythms of the interactions. First of all, the diagram reveals how the driver's and the remote passenger's journeys situate in multiple spots of the continuum line, going from the pure real world of frame 1- the physical selection of a Co-Drive stop performed by the driver- to the virtual reality of frame 6- the shared car trip by the remote passenger. Second, it reveals how the two actors' journeys are deeply intertwined as the experience unfolds: the driver starts placing a Co-Drive stop, then the remote passenger wanders in the virtual Atlas and chooses the stop as departure point of her/his trip, and so on with the next interaction.

In the next section, I will deepen into the perspectives elicited by the XR experience diagram and, by making use of the HCI concept of interactional trajectories, I will trace the single users' journeys to come up with an early-stage prototyping strategy.

3.3.2 Interactional trajectories and seams

Interactional trajectories were conceptualized by Benford et al. [54] to understand complex user experiences that extend over space and time and involve multiple roles and interfaces. Inspired by emerging studies of tangible interfaces and interactions in cultural and social settings (museums and galleries), they suggested that user journeys should maintain a sense of coherence and connectedness as a whole, as users were passing through different places, times, roles and interfaces. By looking at user journeys with the lens of trajectories, the focus is drawn towards the narrative shaping and steering trajectories, the encounters among people, and *"all the interesting things that occur along the way"* [55]. I think that the concept of trajectories could support our Co-Drive study in the specific attempt of moving away from discrete, on device, AR/VR interactions towards a more continuous XR experience.
As a next step, I traced the Co-Drive users' trajectories onto the XR experience diagram by connecting the frames in a narrative order, and thus deepening the linear user journeys by the "virtuality dimension" (Fig. 3.2).

The result was that gaps are revealed both within a single trajectory and across the two trajectories.
Single trajectory: physical and virtual environments appear to be connected into various configurations and key transitions should ensure the continuity of the XR experience. Sometimes the hybrid spaces are adjacent, with participants moving from one to the other in sequence. This is visible in frames 1 and 3 of Fig. 3.2, when the driver places a Co-Drive stop in the real world and later s/he spots the remote passenger's avatar at that stop. Sometimes the physical and virtual environments are "remote but connected", with participants communicating between them. This is visible in frames 4 and 6 of Fig. 3.2 , when the remote passenger virtually moves from from her/his home into the drivers's car, wearing a

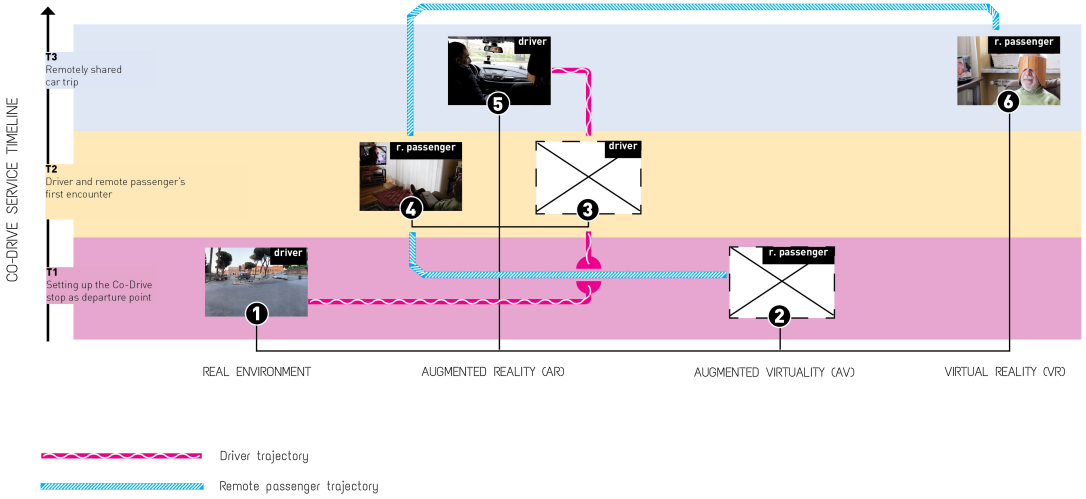


Figure 3.2: The trajectories of the driver and the remote passenger are traced onto the XR experience diagram.

VR headset.

Across the two trajectories: the trajectories show how the user and driver journeys interleave along the hybrid spaces. This is the case in frames 1 and 2 of Fig. 3.2, when the driver journey interrupts after the creation of a Co-Drive stop, and the action of the remote passenger, placing the own avatar at that stop, is inserted next.

As trajectories contribute to revealing gaps both within individual and across multiple users' trajectories, I think that it is even more urgent to switch from a XR prototyping approach which focuses on discrete on-device interactions, towards a prototyping strategy that takes account of the whole experience and the emerging gaps among interactions. Previous literature has been referring to gaps within ubiquitous system as *seams* and various, even opposite, approaches have been suggested on how to deal with them, ranging from hiding to revealing and exploiting them for the sake of the experience. As Chalmers and Galani pointed out [56], interactions may become seamless and unproblematic, even if the differences, boundaries and

seams in media are objectively perceivable. They theorised and experimented *seamful design*, an approach which takes advantage of the gaps and heterogeneity in order to give people space to accommodate and appropriate the media within their social interactions and local environment. In the spirit of the seamful design approach, I focus on the seams emerged in the Co-Drive experience as an opportunity for the design of an early-stage prototyping strategy.

3.3.3 Isolating prototyping interventions

At an early prototyping stage, dealing with the seams within a complex interactive system may be challenging. Just relying on the technological development of the system interfaces towards immediate connection through hybrid spaces, synchronous interactions and computational capacity is not even a possibility because of the nature of rapid prototyping itself. Actually, I argue that it may not be the right way to go when the aim of the rapid prototyping is to explore how people will respond to the experience: what at first can be considered as drawbacks for the continuity of a complex XR experience, like the presence of multiple media and shortage of working technology, instead can contribute to shift the prototyping attention from single on-device interactions onto the social and cultural nature of the users experience.

Following the deconstruction of the Co-Drive XR experience and the tracing of the users' trajectories, I isolated key interactions from the user journeys and addressed them as separated prototyping interventions. By doing so, I magnified the experience seams, aiming at observing how people would weave the Co-Drive interactions within their own network of relationships and everyday context. The selection of the prototyping interventions was done according to: i) the appropriateness of the fidelity I could reach within a rapid prototyping process (for instance, this made me exclude the embodiment of the remote passenger inside

the car); ii) the engagement of both the users, individually and together; iii) touching upon the key phases of the experience. Three key interactions were selected to be prototyped as separated interventions: 1/ the placement of the Co-Drive stops by the driver (frame 1 in Fig. 3.2); 2/ the booking of a Co-Drive trip by the remote passenger (frame 2 in Fig.3.2); 3/ the shared car trip by the driver and the remote passenger (frame 5 and 6 in Fig. 3.2).

3.4 The prototyping plan during Covid-19

To resume, our early-stage prototyping strategy progressively took shape as the following process: deconstructing the XR experience –> tracing users' trajectories –> isolating prototyping interventions –> running the interventions –> reflecting on people's accommodation and appropriation of the experience.

	PROTOTYPING INTERVENTIONS	PARTICIPANTS		TIMEFRAME
		Drivers	Remote passengers	Sept2020 – June2021 / Jan2021 – June2021 / July2021 – Nov2021
1	The placement of a Co-Drive stop	6		
2	The booking of a Co-Drive trip		6	
3	The shared car trip	3	4/5	

Table 3.1: Recruitment and timeframe of the prototyping process.

As the prototyping process proceeded in separated interventions, the orchestration and facil-

itation of each intervention was instrumental to maintain the participants aligned, aware of their relative position in the experience and engaged in the overall narrative. The interventions happened during the Covid-19 pandemics in Italy and required a special organization to comply with the social distance guidelines and the concerns brought about by the elderly participants' relatives of limiting occasions of contamination. The timeframe for the prototyping process encompassed 15 months, from september 2020 to november 2021, a considerably long time due to the fact that Covid-19 pandemics in Italy slowed down or even blocked the experimentation. The interventions took place sequentially and involved a variable number of people, according to the aim of the intervention, as well as the contingencies of the pandemics (Table 3.1).

Concerning the participants, 6 persons aged from 75 to 91 y.o. were recruited as remote passengers, 5 women and 1 man. One participant withdrew in intervention 3 for reasons linked to the pandemics. The prevalence of women in the recruited group reflects the range of seniors attending the day care, hence the actual Italian demographics according to which women are living longer and healthier than men [57]. They all used to attend a day care center in Rome, where professional caretakers and social workers organize leisure activities, cognitive and physical training and, from time to time, daily or weekend excursions by bus. The group was recruited based on individual good cognitive abilities, since none of them suffer from a major cognitive decline. The only man in the group had suffered from a stroke and since he has difficulties in spoken communication, during the study session his wife was assisting him and supporting the conversation.

The drivers instead were recruited through an online open call which was spread through the researcher's personal network, the project website and social media.

The sessions were run by myself, the researcher in the role of the facilitator, and by a social worker affiliated to the elderly care center. The role of social worker was essential in time of

pandemics. He acted as the host of the sessions and occasionally as the physical twin of the researcher, when the Covid-19 restrictions in Italy prevented the seniors and the researcher to meet physically, but still only the social worker was allowed to reach the senior at home for routine care.

Isolating prototyping interventions required the researcher to come up with as many prototyping scripts and artifacts as the number of interventions themselves. Prototyping artifacts consisted of props, tools, video prototypes, and interactive applications, and ranged from low to medium-high fidelity. The artifacts were designed to be the most appropriate way to engage the specific user in the experience. This was particularly important in respect to the remote passengers who participated in the prototyping, since they were all senior adults with no familiarity with augmented or virtual reality.