PEPR EXPLORATOIRES
PROJET CIBLE
2022

PROGRAMME ENSEMBLE

DOCUMENT PRESENTATION PROJET

CATS

Acronyme	**CATS**
Titre du projet en français	*Collaboration À Travers des eSpaces hétérogènes (CATS)*
Titre du projet en anglais	*Collaboration Across heTerogeneous Spaces (CATS)*
Mots-clefs	computer-mediated collaboration; heterogeneous spaces; interactive environments; collaborative user experience; human-computer interaction; virtual/augmented reality.
Établissement porteur	Université Paris Saclay

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Durée du projet	84 Mois		
Aide totale demandée	5.16 Million €	**Coût complet**	37.24 Million €

Liste des établissements du consortium :

Établissements d'enseignement supérieur et de recherche	***Secteur(s) d'activité***
Université Grenoble Alpes	*Informatique, SHS*
Université Paris-Saclay	*Informatique, SHS*
Institut Mines-Télécom	*Informatique, SHS*
Sorbonne Université	*Informatique, SHS*
Université Claude Bernard Lyon 1	*Informatique, SHS*
Université de Lille	*Informatique, SHS*
Université de Toulouse 3	*Informatique, SHS*
Université Gustave Eiffel	*Informatique, SHS*
Université d'Evry	*Informatique, SHS*
Université de Strasbourg	*Informatique, SHS*
ENAC	*Informatique, SHS*
ENSAM	*Informatique, SHS*
Université de Lorraine	*Informatique, SHS*
CESI	*Informatique, SHS*

Organismes de recherche	***Secteur(s) d'activité***
CNRS	*Informatique, SHS*

INRIA	*Informatique, SHS*

Autres partenaires	Secteur(s) d'activité
CEA	*Informatique, SHS*

Résumé du projet en français (Non Confidentiel – 4000 caractères maximum, espaces inclus)

Les défis scientifiques abordés par ce projet proviennent d'un changement d'échelle le long des trois dimensions suivantes des espaces de collaboration : 1) diversité des utilisateurs, 2) diversité des dispositifs/modalités d'interaction, et 3) complexité des ensembles de données, des tâches et des environnements. Un quatrième défi consiste à gérer les transitions dynamiques entre les espaces de collaboration. Ce défi nécessite une approche intégrative des trois dimensions d'un espace de collaboration. En effet, la question de recherche fondamentale est de concevoir des espaces de collaboration qui permettent une collaboration continue et transparente afin d'unifier les collaborations à distance et en face à face, les collaborations étroitement couplées, ainsi que les collaborations de groupe, dans des sous-groupes ou des apartés spontanés.

La percée attendue est la définition d'espaces de collaboration mixtes où les utilisateurs ont le plein contrôle et qui offrent des expériences multi-utilisateurs riches en possibilités et flexibles.

Résumé du projet en anglais (Non Confidentiel – 4000 caractères maximum, espaces inclus)

The scientific challenges addressed by this project come from a change of scale along the following 3 dimensions of collaboration spaces: 1) diversity of users, 2) diversity of interaction devices/modalities, and 3) complexity of datasets, tasks and environments. A fourth challenge is to handle the dynamic transitions between collaboration spaces. This challenge requires an integrative approach with the 3 dimensions of a collaboration space. Indeed, the fundamental research question is to design collaboration spaces that allow for continuous and seamless collaboration in order to unify remote and face-to-face collaborations, tightly coupled and loose collaborations, as well as group collaborations, in spontaneous subgroups or asides.

The expected breakthrough is the definition of mixed collaboration spaces where users are in full control and that provide rich and flexible multi-user experiences.

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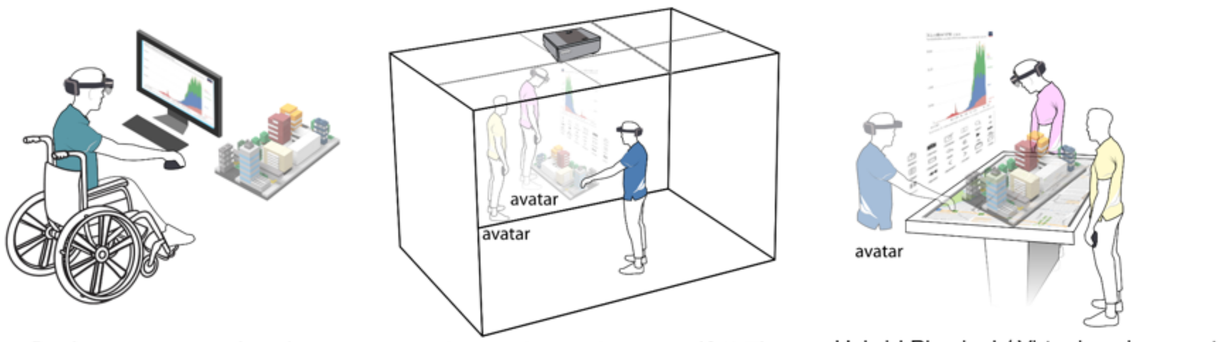
1. Context, objectives and previous achievements

1.1. Context, objectives and innovative features of the project

The situations in which several participants communicate and collaborate at the same time, remotely or face-to-face, are many and varied: project review, hybrid teaching, telesurgery, crisis management, family reunion in a pandemic situation, etc. Such collaboration among participants engaged in various forms of activity and work takes place in a *collaboration space*. The unprecedented, extensive and sometimes unexpected use of collaboration spaces during the COVID-19 pandemic is the result of three decades of research on computer-mediated collaboration. For example, keeping a Zoom or Skype video call continuously open to maintain a sense of shared presence mimics the research prototype of Portholes[1], a media space created back in 1992.

An example of a heterogenous collaboration space with four participants, two being co-located.



Desktop augmented environment | Immersive environment (CAVE) | Hybrid Physical / Virtual environment

We are however at a turning point due to a change of scale. The recent technological developments in sensing technologies, displays (large, immersive, mobile, wearable), networking and visualizations tools has led to increasingly heterogeneous physical and digital collaboration spaces where participants with different interaction devices and modalities must be able to collaborate efficiently, raising the critical issue of interoperability between these devices and modalities. What was once confined to industrial and academic laboratories is now becoming increasingly available to a wider audience. It is paramount that these collaboration spaces are accessible to the widest diversity of users to ensure equal access to collaborative activities, education and jobs. Moreover, the wider availability of these technologies is accompanied by an increase in the diversity but also complexity of activities that require collaboration, such as the analysis of large heterogeneous data sets that cannot be thoroughly explored and understood by any single person.

The expected breakthrough is the definition of mixed collaboration spaces where users are in full control and that provide rich and flexible multi-user experiences. These spaces must adapt to the diversity and dynamicity of the interaction capabilities of each participant, to their physical and digital environments, and to the different modes of collaboration. These collaboration spaces will support more and more of our activities as well as change them. We need to better understand these phenomena, some of which are general while others are domain-specific, in order to create appropriate solutions. The design of these new mixed collaboration spaces, seamlessly integrated into our private and professional lives and into the social fabric as well as the study of their impact on changes in collaboration patterns require interdisciplinary work involving social, management scientists, psychologists, ergonomists, domain tasks experts (e.g. mechanical engineering), and computer scientists (human-computer interaction, software engineering, computer graphics, network and multimedia, virtual/augmented reality), all engaged in this axis.

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[1] Harrison, S. (Ed.). (2009). Media space 20+ years of mediated life. Springer Science & Business Media.

1.2. Main previous achievements

The project will benefit from the previous experience and contributions of the research groups of the consortium in the different required fields: ergonomics and psychology, Augmented/Virtual Reality and Human-Computer Interaction.

Ergonomics and Psychology: The project will build upon the partner's research on the design and assessment of emerging technologies like Virtual, Augmented and Mixed Reality environments for several years (e.g. Burkhardt, Perron & Plénacoste, 2006; Guegan, Nelson, Lamy & Buisine, 2020; Bourgeois-Bougrine, Bonnardel, Burkhardt, Thornhill-Miller, Pahlavan, Buisine, Guegan, Pichot & Lubart, 2022; Franco, Loup-Escande, Loiseaux et al. 2023) as well as on collaborative work and learning either in face-to-face situations or through innovative computer-mediated systems (e.g. Détienne, Baker & Burkhardt, 2012 ; Safin, Détienne, Burkhardt, Hébert & Leclercq, 2019 ; Milleville-Pennel, Mars & Pouliquen-Lardy, 2020). The human-factors and ergonomics researchers in the partner teams build on a long-standing experience of interdisciplinary projects involving human and social sciences, design sciences, and human-computer interaction in emerging technologies for collaboration.

Augmented, Virtual and Mixed Reality *(AR/VR/Mixed Reality)*: The project will build upon a strong experience of the partners on augmented/virtual reality technologies and methodology. There are several locations in France gathered within the Equipex+ CONTINUUM project with immersive equipments, such as Immerstar in Rennes, Playground in Grenoble, CERV in Brest, InVirtuo in Strasbourg or EVE in Orsay. The partners will benefit from these facilities as well as their strong expertise recognized at an international level. Therefore, they have developed these last years novel interaction techniques (Bailly et al. 2020; Baloup et al. 2021) and original interfaces (Plasson et al. 2022), innovative multi-sensory feedback (Salazar et al. 2020, Vizcay et al. 2022) and several virtual scenarios and collaborative environments (Vailland et al. 2021). These contributions have been published in the most well-known conferences and journals in virtual and mixed reality and provide a solid scientific basis for the project to design novel contributions dedicated to collaborative spaces.

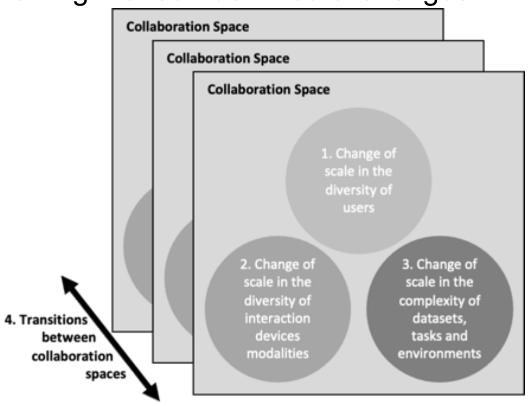
Human-Computer Interaction*(HCI):* The project will build upon the experience of its partners on the design and development of novel interaction techniques, modalities and devices for collaborative heterogeneous spaces. The project will benefit from existing interaction devices for multi-display environments, such as TDome (Saidi et al., 2017) or PickCells (Goguey et al., 2019). The consortium members have also developed multiple techniques for spatial interaction, such as novel spatial menu techniques (e.g. HoloBar (Saidi 2021), Head-controlled menu (Bailly et al., 2019)) or pointing techniques (Plasson et al. 2021). Finally, several partners will contribute with novel visualization techniques for immersive environments, such as embedded visualizations. These contributions, which have been published in top-tier venues, ensure the availability of a wide variety of interaction techniques of interest for collaborative purposes, and whose combination and interlink can be explored in the project.

More specifically on the pilot institution: Augmented, Virtual and Mixed Reality / Human-Computer Interaction
Université Paris-Saclay's Laboratoire Interdisciplinaire des Sciences du Numérique (LISN) hosts an HCI department with 6 groups, including Ex-Situ (leader: Wendy Mackay), ILDA (leader: Emmanuel Pietriga), AVIZ (leader: Jean-Daniel Fekete), and VENISE (leader: Christian Sandor). All of these teams have published extensively in the area of AR/VR/Mixed Reality and HCI with best paper awards at leading conferences (ACM UIST, ACM CHI, IEEE ISMAR, IEEE VIS).

2. Detailed project description

2.1. Project outline, scientific strategy

The scientific challenges addressed by this project come from a change of scale along the following 3 dimensions of collaboration spaces: 1) diversity of interaction devices/modalities, 2) diversity of users, and 3) complexity of datasets, tasks and environments. A fourth challenge is to handle the dynamic transitions between collaboration spaces. This challenge requires an integrative approach with the 3 dimensions of a collaboration space. Indeed, the fundamental research question is to design collaboration spaces that allow for continuous and seamless collaboration in order to unify remote and face-to-face collaborations, tightly coupled and loose collaborations, as well as group collaborations, in spontaneous subgroups or asides. The scientific strategy of the project will be decomposed into four axes, following the four identified challenges.



Axis 1.1: Change of scale in the diversity of interaction devices/modalities: heterogeneous collaboration spaces

The advent of fabrication techniques such as additive manufacturing and printed electronics (e.g., smart materials, ultrasound mid-air haptic) as well as the emergence of a variety of commercially available multi-sensory devices pave the way for a very large space of possibilities in terms of **input and output interaction devices**. For example, output visual devices range from smartwatches and hand-held screens to tabletops, head-mounted displays, wall-sized displays and CAVEs. By creating the conditions for interoperability among these technologies, we will open up new design solutions for heterogeneous collaboration spaces.

The scientific challenges involve understanding the impact of these heterogeneous multimodalities on the users of these collaboration spaces. For collaboration spaces that replicate human behavior/interaction found in our daily actions in the physical world, the key issue is to ensure the transfer of skills from real to virtual and from virtual to real, blurring the boundary between the two. The heterogeneity of devices will require revisiting the concepts of presence, common ground and group awareness. This includes investigations of interaction modalities (e.g., gestures, sound or haptic) in fragmented physical, 2D and 3D virtual environments. This will lead to the creation of new collaboration spaces supporting very different types of experiences than in the real world.

Axis 1.2: Change of scale in the diversity of users: collaboration spaces for all

Despite huge progress in communication technology, remote collaboration remains often hard and less satisfactory than face-to-face, resulting in less engagement, motivation or perceived support, and more collaboration failures. Apart from geographic distance, other factors come into play such as the diversity of collaborators' sensory, motor and cognitive capabilities, the diversity of the team members' roles, and the diversity of the stakeholders' cultural background and familiarity with technology. A solution is to adopt personalized representations (e.g., avatars) controlled by the users

and employing part or whole of the users' body to interact with digital content and to support collaboration. However, this approach is also likely to create barriers to accessibility. Finally, there is no satisfying approach to assess the resulting quality of participants' experience as the collective collaborative processes scales up.
Since the diversity of users has been largely ignored until now, we will develop inclusive methods and design solutions for collaborative tools so that the resulting technology is accessible and useful to all members of society and consistent with human diversity (cf. Universal Design / Design for All). Moreover, to foster engagement in remote collaborative interaction, we will provide measures of the impact of embodiment on users and innovative techniques for controlling an avatar. Finally, based on an interdisciplinary approach, we will create a framework for describing and measuring the quality of collaborative experiences.

Axis 1.3: Change of scale in the complexity of datasets, tasks and environments: collaboration in the large
This axis focuses on the grand challenge of scaling up current collaborative data analysis practices to leverage the possibility of dealing with 1) massive datasets, 2) very complex collaborative tasks, and 3) large and hybrid collaboration environments.
1) The ever growing adoption of sensors generates large amounts of data (e.g. energy consumption), which are crucial to help stakeholders in decision-making processes. This is challenged by the lack of a coherent and broadly applicable visualization and interaction approach to make collaborative analytics systems productive and usable in real world scenarios.
2) Essential real world collaborative scenarios, such as crisis management, involve several heterogeneous actors, operators, analysts and decision makers in very complex collaborative tasks. These tasks require the orchestration and piloting of collaborative actions (e.g., crisis responses) with actors operating spread over various physical locations (e.g. fireman in the field). The challenge is to better understand how these well-known collaborative activities will evolve with the advent of novel collaborative tools, and to create the necessary conceptual models and software tools to support these activities.
3) Collaboration environments can now take different forms (virtual such as the MetaVerse, physical or hybrid), which challenges how to develop realistic, real-time and large hybrid environments, while studying and understanding their impact on the collaboration dynamics. We need tools to adapt current desktop-based content to these environments, to acquire and track the objects and persons in the environment, to remove the latency and ensure real-time collaboration, and human models of the group dynamics within these novel spaces.

Axis 1.4: Transitions between collaboration spaces: dynamic collaboration space
This axis aims at designing a holistic approach for handling the transitions between dynamic collaboration spaces. While various collaboration spaces have been designed these last decades, in correlation with the explosion of new technologies for immersing users in virtual or augmented environments, the transitions between these collaboration spaces have been scarcely addressed. Collaboration spaces are dynamic by nature and this axis focuses on the design and evaluation of transitions. The breakthrough novelty of this axis is that it needs to address both spatial and temporal transitions simultaneously to encounter the dynamicity of the collaboration spaces. Our holistic approach aims at addressing in symbiosis (1) the design of transitions between heterogeneous collaboration spaces, (2) the design of transitions between collaborative users and (3) the design of transitions between complex spaces. Taken together, these three objectives will pave the way for designing the transitions in any new collaborative world, with a novel generation of transition approaches able to scale to the dynamicity of the collaborative spaces and the users.

2.2. Scientific and technical description of the project

We hereafter describe for each Axis its work packages (WPs) and deliverables (Ds).

Axis 1: Change of scale in the diversity of interaction devices/modalities: heterogeneous collaboration spaces

This axis will cover the challenges of heterogeneous collaboration spaces along three dimensions: the interface presentation and organization in heterogeneous display spaces (WP1.1); the multi-sensory feedback across heterogeneous spaces (WP1.2); and the heterogeneity of interaction devices, modalities and techniques (WP1.3).

***WP1.1*: Interface presentation and organization in heterogeneous display spaces**. These heterogeneous collaboration spaces involve multiple types of display technologies: mobile and wearable small displays; desktop displays; augmented reality and virtual reality head-mounted displays; large display walls; or immersive caves, among others. The diversity and multiplicity of display technologies leads to content presentation and organization challenges, e.g. how to best present the information (e.g. UI widgets, menus, shared content) to support in-situ or distant collaboration across these display spaces. However, there are still multiple unanswered challenges, such as how to best design spatially situated interfaces, how to place interfaces accurately in space or how to integrate current collaboration practices in these novel interface layouts.

***WP1.2*: Multi-sensory feedback for heterogeneous collaboration spaces.** The goal of this WP is to design novel multi-sensory feedback dedicated to collaborative tasks within heterogeneous collaboration spaces. The level of fidelity as the accuracy with which real-world experiences and effects are reproduced by a computer system is the key issue in enabling realistic multimodal interaction and multisensory feedback which, in turn, ensures the transfer of skills from the real to the virtual and vice versa, blurring the boundary between both worlds. Within heterogeneous collaboration spaces, the challenge is to find which multisensory feedback(s) (visual, audio or haptic) could be generated to provide appropriate information for improving the collaboration. This last decade has seen the emergence of a new generation of immersive technologies with head-mounted displays available for the general audience or wearable haptic devices that could be mounted on different body parts (Pacchierotti et al. 2017). These new technologies bring novel opportunities for designing multi-sensory feedback dedicated to collaborative actions within mixed environments.

***WP1.3*: Interaction devices, modalities and techniques for collaborative interactive tasks.** The goal of this WP is to design, develop and evaluate novel interaction devices, modalities and/or techniques to foster interaction in collaborative heterogeneous environments. These spaces need to support the human behaviors and interactions found in our everyday actions in the physical world. However, the heterogeneity of interaction approaches can be an obstacle to effective collaboration. In particular, the WP will focus on investigating the complex challenges of how to ensure object and widget selection, manipulation and positioning, as well as user navigation, with heterogeneous interaction approaches, when such objects can be either physical or virtual according to the user's environment. For instance, one user can be pointing at a physical object or screen in a real-world environment, while the object's virtual counterpart (virtual object or window) must be manipulated by another user in a VR environment, using completely different interaction modalities or devices. This is typically the situation of distant guidance in augmented maintenance scenarios.

Deliverables of Axis 1:
D1.1 Methods for presenting and organizing content in heterogeneous display spaces.
D1.2 Multi-sensory rendering modalities and techniques for collaboration spaces.

D1.3 Interaction techniques for collaborative interactive tasks.

Axis 2: Change of scale in the diversity of users, collaboration spaces for all

This axis will address the challenges of ensuring that collaboration spaces are available for all users, along three dimensions: the diversity of users' capacities, disabilities and profiles (WP2.1); the embodiment of user's avatars (WP2.2); and the measure of collaborative synchronous experiences (WP1.3).

WP2.1: Diversity and evolutivity of capacities and disabilities, expertise, role, social context and culture. Despite huge progress in communication technology, remote collaboration remains often hard and less satisfactory than face-to-face, and is not yet fully accessible, resulting in less engagement, motivation or perceived support, and more collaboration failures. The first goal of this WP is to develop inclusive methods and design solutions for collaborative tools so that the resulting technology is accessible and useful to all members of society and consistent with human diversity (cf. Universal Design / Design for All). Apart from a geographic distance and individual capacities, other factors come into play such as the diversity of the team members' roles, and the diversity of the stakeholders' cultural background and familiarity with technology. How diversity and asymmetry are supported - particularly in co-localized reference situations - and how they could be supported efficiently in remote or hybrid synchronous collaborative situations are at the heart of this WP. This will be carried out with the development of tools and functions to adapt collaborative environments to these specificities, and the evaluation of their impact in different situations and representative use cases of synchronous collaboration.

WP2.2: Embodiment, control and properties of users' avatar for collaboration. The research on users' representations (often referred to as their "avatar') is amongst the most promising path to identify more efficient solutions in order to foster engagement and facilitate collaborative activities in synchronous remote situations. The design of avatars and techniques to control these avatars more effectively for collaboration should go beyond initial designer intuition and/or trial-and-error development, to build on and contribute to the development of knowledge about the social, cognitive and emotional dimensions that underpin effective real-time interaction and collaboration. Thus, this line of research deals with embodiment, and the increase in propositions of environments where users employ part or whole of their body to interact with digital content and to support collaboration and cooperation. This includes the collection of evidence about the effect of embodiment and the sense of agency, as well as the development and assessment of innovative and more appropriate techniques to enable the users to control their avatar in collaborative interaction, possibly including the capture and expression of emotions, attention etc.

WP2.3 Diversity, specificity and multidimensionality of synchronous collaboration experience. Still, we have no entirely satisfying framework that supports the understanding and assessment of the quality of participants' collaborative experience in synchronous situations. First, many open questions still remain, for example: what dimensions of collaboration are affected by the diversity and evolutivity of participants working together, by space hybridization or also by the transition between spaces of collaboration? What are the needs for sharing common understanding in cross-reality collaboration by the various participants? To what extent such hybrid spaces are useful to share and develop knowledge? Second, while the research disposes of numerous theories and techniques to measure how systems, interaction techniques and devices can affect users' actions, performance and satisfaction, they mostly reflect impacts at the "micro" individual user scale - focusing on a restricted subset of fine-grained interactions- rather than at the "macro" scale, i.e. at the collective - team - collaborative process and experience scale. Developing such a "macro" framework constitutes a critical interdisciplinary challenge for research and is transversal to the project and should be confronted with frameworks and studies targeting collaborative experience in the other covered situations (long-term collaboration, collaboration with artificial agents, large-scale collaboration...).

Deliverables of Axis 2:
D2.1 Design for diversity and adaptation of hybrid environments to support heterogenous participation: Components, Methods and guidelines.
D2.2 Design and assessment of embodiment techniques and users' avatar to support synchronous collaboration
D2.3 Models of / evaluative approaches dedicated to synchronous collaborative experience
D2.4 Repository of synchronous collaboration uses cases

Axis 3: Change of scale in the complexity of datasets, tasks and environments: collaboration at large

This axis will address the challenges related to the collaboration at large along three dimensions: the collaborative analysis of massive datasets (WP3.1); collaboration for very complex tasks (WP3.2); and complex spatial hybrid environment (WP3.3).

WP3.1: Collaborative analysis of massive datasets. The ever-growing adoption of sensors generates large amounts of data (e.g. energy consumption), which are crucial to help stakeholders in decision-making processes. Traditional desktop visualizations need to be adapted to support collaborative sensemaking and take profit from the large display space. The rapidly growing body of research on Immersive Analytics [Ens 2021] has started to show the benefits of immersive data visualization to enhance collaborative decision support. These advances are challenged by the lack of a coherent and broadly applicable visualization and interaction approach to make collaborative analytics systems productive and usable in real world scenarios. The goal of this work package is to create broadly applicable visualization and interaction approaches with large datasets.

WP3.2: Collaboration for very complex tasks. Essential real world collaborative scenarios, such as crisis management, involve several heterogeneous actors, operators, analysts and decision makers in very complex collaborative tasks. These tasks require the orchestration and piloting of collaborative actions (e.g., crisis responses) with actors operating spread over various physical locations (e.g. fireman in the field). The challenge is to better understand how these well-known collaborative activities will evolve with the advent of novel collaborative tools, and to create the necessary conceptual models and software tools to support these activities. The goal of this work package is to create the necessary conceptual models and software tools to support these activities.

WP3.3: Complex spatial hybrid environment. Collaboration environments can now take different forms (virtual such as the in the MetaVerse, physical, or hybrid). It is an unsolved problem of how to rapidly create hybrid environments that combine real and virtual objects. We envision an infrastructure that enables users to very rapidly "beam" (or teleport) real objects into virtual environments to create hybrid environments. Ideally, we would like to support beaming of: humans, their complete surrounding environment, as well as high-quality reconstructions of work pieces. The goal of this work package is to develop realistic, real-time, and large hybrid environments for collaboration.

Deliverables of Axis 3:
D3.1 Visualization & Interaction techniques to support collaborations on massive datasets
D3.2 Conceptual models and tools to support complex interaction tasks

D3.3 A widely applicable hardware+software platform for beaming/teleporting users, artifacts, and environments to remote locations.

Axis 4: Transitions between collaboration spaces - dynamic collaboration space

Given the opening of the technologies to a general audience these last ten years, we need to reconsider the methods for collaborating within dynamic spaces, revisiting the continuum between real and virtual environments (Skarbez et al. 2021). The main challenge of this Axis relies on the in-depth modification of the use of collaboration spaces in a dynamic manner, aiming at interactive transitions between the different spaces. The dynamicity of a collaboration space can take different forms. Transition between collaboration spaces will thus be studied from the group's and user's point of view by considering both the social aspects (group of users), the cognitive aspects (tasks at hand) and the perceptual/action aspects (human perception and motor control).

WP4.1 Transitions between the interactive collaborative spaces. Given the wide diversity of collaboration spaces (see Axis 1.1), we need to leverage novel user interaction techniques and devices to address the dynamic transitions between collaborative spaces. These interaction techniques and devices should reinvent the collaborative manipulation, selection, exploration and navigation within heterogeneous spaces by addressing the specificities of the users and their environment during the transitions between spaces. Various environments, mixing virtual and real components could cohabit and these multiple "mixed reality layers" of collaboration spaces should be addressed through the design of interaction techniques and devices able to translate the users' actions between spaces and to allow them an appropriate control of their actions between spaces.

WP4.2 Transitions between users, groups of users and group dynamics. Given the wide specificities of users collaborating together (see Axis 1.2), we need to address the transitions of collaborative tasks between users, in order to take into account their intentions and actions. These transitions should consider the personal space of each user and should be able to have them cohabited in a smooth and comprehensive manner for every user collaborating in a given task and a given environment. These transitions should also handle the changes of users within a scenario while not breaking the collaboration experience.

WP4.3 Transitions between large and complex environments. Given the complexity of tasks, environments and datasets (see Axis 1.3), we need to leverage novel methods to facilitate the transitions between complex collaboration spaces. Transitions should be redesigned for addressing both the temporal and spatial dynamicity of the spaces. The diversity of the objects, users and tasks within these environments could be taken as an advantage since the wide amount of interaction possibilities could ease the implementations of appropriate transitions.

WP4.4 Evaluation and generalization of the transitions. A thoughtful evaluation of the different transitions will be systematically implemented and iteratively consolidated throughout the project. This WP will focus on characterizing a transition. Based on these characteristics, the efficiency of a transition will also be defined. Thus, beyond maximizing user performance and allowing continuous/seamless collaboration, different aspects need to be considered towards a "*good user experience*" (Fallman 2011, The new good: exploring the potential of philosophy of technology to contribute to human-computer interaction), a "good collaboration experience" and a "good transition experience". This WP will be achieved in thorough interactions with the other projects of the eNSEMBLE program.

Deliverables of Axis 4:

D4.1 Characterization space of transitions quality between collaborative spaces
D4.2 Interactive techniques to facilitate transitions between collaborative spaces
D4.3 Use cases of transitions between collaborative spaces illustrating transitions along the three dimensions: collaborative spaces, users and complex environments.

2.3. Planning, milestones and KPI

We detail in the following table our milestones along the two PEPR phases: a Maturation phase from year 1 to 3 followed by a Concretization phase from year 4 to 8.

Phase	Deliverables Milestone	Year	Results
Maturation	**M1**	1	Initial repository of uses cases (cross axis)
	M3	3	Initial set of presentations, rendering and interaction modalities and techniques (Axis 1: D1.1, 1.2, 1.3) Initial set of methods and guidelines to design collaborative spaces for all (Axis 2: D2.1, 2.2) Initial proof-of-concept platform (Axis 3: D3.3) Update repository uses cases (cross axis)
Concretization	**M5**	5	Intermediate set of presentations, rendering and interaction modalities and techniques (Axis 1: D1.1, 1.2, 1.3) Intermediatel set of methods and guidelines to design collaborative spaces for all (Axis 2: D2.1, 2.2) Intermediate proof-of-concept platform, initial visualization approaches (Axis 3: D3.1, D3.3) Initial characterization space of transitions (Axis 4: D4.1) Initial set of techniques to facilitate transitions (Axis 4: D4.2) Update repository uses cases (cross axis)
	M7	7	Final set of presentations, rendering and interaction modalities and techniques (Axis 1: D1.1, 1.2, 1.3) Final set of methods and guidelines to design collaborative spaces for all (Axis 2: D2.1, 2.2) Models of evaluative approaches (Axis 2: D2.3) Final proof-of-concept platform, models to support complex tasks visualization approaches (Axis 3: D3.1, D3.2, D3.3) Final characterization space of transitions, techniques to facilitate transitions and use cases (Axis 4: D4.1, D4.2, D4.3) Update repository uses cases (cross axis)

The project will produce the following KPIs - the CATS specific ones are in bold - measure its success:

KPI		Risk	Corrective measures
		Scientific KPI	
1	**Number of publications in major venues**	Low	• Increase the communication of deadlines of conferences and journals relevant to the focused project
2	Number of Interdisciplinary publications	Medium	Increase the ratio of funded PhD thesis involving interdisciplinary co-advising

			offer dedicated training to value the work in different disciplines Increasing the ratio of funding dedicated interdisciplinary micro-projects
Valorization KPI			
3	Number of links / projects with industry partners	Medium	Participate to industrial events Increase communication towards industrials
Training KPI			
4	Number of co-advised PhD thesis	Low	Favor open-call projects proposing PhD co-advising
5	Number of co-advised PhD thesis with advisors from different fields	High	Favor open-call projects proposing PhD co-advising with advisers from different fields
6	**Number of Master Internships in the scope of the PEPR**	Medium	Dedicate more funding of master grants in the Targeted Projects
8	Seminars, workshops	Medium	● Dedicate more funding to the animation ● Work in close collaboration with the pilot institutions and partners
Technical KPI			
9	Number of demonstrators	Medium	Dedicate more funding to engineering
Communication and Dissemination KPI			
10	Number of dissemination actions	Low	Encourage the community to communicate
11	Number of articles in the press	High	Reinforce the dissemination actions with the Communications Board
International KPI			
12	Number of international actions (visitors, events - workshops, schools, masters, …)	High	Encourage the organization of workshops in international events (conferences, schools, etc.)
Human KPI			
13	Gender diversity	Medium	● At equal level, choose women and non-binary persons ● Encourage women and non-binary to apply
Leverage KPI			
14	Number of awards (ERC, IUF, Best papers, etc.)	Low	● Encourage members of the program to apply ● Develop a program to mentor applicants
15	**Number of funded projects (local, national, international)**	**High**	**● Encourage the members of the program to apply** **● Develop a program to mentor applicants**

3. Project organization and management

3.1. Project coordinators

The project is coordinated by Jean-Marie Burkhardt (Univ. Gustave Eiffel), Christian Sandor (Univ. Paris-Saclay) and Marcos Serrano (Univ. Toulouse 3). The WPs will be managed by the three coordinators along with a fourth coordinator, Maud Marchal (INSA Rennes).

Jean-Marie Burkhardt (**Psychology & Ergonomics)** is research Professor at LaPEA (Univ. Gustave Eiffel & Paris Cité Univ.). After a Master's Degree in Ergonomics (1992) and a Master's Degree in Cognitive Psychology (1993), he obtained a Ph.D. in Cognitive Ergonomics from the Paris 5 university Paris in 1997, and an accreditation to supervise research (HDR) from the Aix Marseille University in 2010. Dr. Burkhardt research interest is twofold: (1) the evaluation and development of emerging technologies, especially in the fields of virtual reality and augmented reality; (2) the psychology of design activities and designers, with a specific interest on the collaborative dimension of design activities and supportive technologies. He was guest co-editor of the special issues on the quality of collaboration of CoDesign: International Journal of CoCreation in Design and the Arts (2012). He has experience in coordinating national and European projects and coordinated the ANSES' working group on health effects of Virtual and Augmented Reality (Burkhardt, Behar-Cohen, Grynszpan et al. 2021). He has chaired the French Association for Research in Ergonomics and Ergonomics Psychology (ARPEGE) since 2021.

Christian Sandor (AR/VR/Mixed Reality) is Professor at Université Paris-Saclay since October 2021, where he is leading the VENISE team at CNRS. Since the year 2000, his foremost research interest is AR, as he believes that it will have a profound impact on the future of mankind. In 2005, he obtained a doctorate in Computer Science from the Technische Universität München, Germany under the supervision of Prof. Gudrun Klinker and Prof. Steven Feiner (Columbia University, USA). He is among the leading AR researchers in the world and has been investigating perceptual issues for AR for over 20 years, including investigations into: Perception of AR X-Ray Vision, enabling users to see through solid objects (Santos et al, 2015); Distance perception (Dey & Sandor, 2014); perceptual differences between AR and VR (Krichenbauer et al., 2017 & 2018), and the modification of thermoception through AR stimuli (Weir, Sandor, Swoboda et al. 2012; Eckhoff et al., 2022). Together with his students, he won multiple awards at premier AR conferences, including IEEE International Symposium on Mixed and Augmented Reality and ACM Symposium on Spatial User Interaction. He has presented several keynotes and has acquired over 2.5 million USD in funding. He has a strong track record of working on commercial products with industrial partners, including Google Inc. (Mountain View, USA), Epson (Nagano, Japan), Samsung (Seoul, Korea), Nvidia (San Francisco, USA), Nokia Research Center (Tampere, Finland), and Canon's Leading-Edge Technology Research Headquarters (Tokyo, Japan).

Marcos Serrano (HCI, AR/VR/Mixed Reality) is Associate Professor at the University of Toulouse and at the IRIT Lab, where he is leading the ELIPSE research group. Marcos joined this position in 2013 and defended his research Habilitation in 2018 with a thesis on Ubiquitous Interaction. His research is dedicated to designing novel interaction techniques in the field of mobile and ubiquitous computing. He is currently leading an ANR JCJC grant on pervasive freeform interfaces (ANR JCJC PERFIN), and has previously coordinated both national and international projects. He was the general chair of the international conference ACM MobileHCI 2021 in Toulouse and is currently the chair of its steering committee. His work is frequently published in top-tier conferences in the field of Human-Computer Interaction.

Maud Marchal (AR/VR/Mixed Reality) is Full Professor in Computer Science at INSA Rennes and IRISA research unit. She is also Junior Member of Institut Universitaire de France since 2018. She works on physically-based simulation since her PhD in 2006 at University Joseph Fourier, Grenoble. Since 2008 and her position at INSA, she has explored and contributed to novel VR applications, gathering her expertise on multi-sensory feedback, 3D interaction techniques and interactive physically-based simulations. She is involved in program committees of major conferences of computer graphics, virtual reality and haptics and Associate Editor of IEEE Transactions on Visualization and Computer Graphics, IEEE Transactions on Haptics and ACM Transactions on Applied Perception. She has been Program Chair of IEEE Virtual Reality Conference in 2018, 2020 and 2021, Program Chair of IEEE Symposium on Mixed and Augmented Reality in 2021 and 2023 and General Chair of ACM SIGGRAPH/Eurographics Symposium on Computer Animation in 2018.

3.2. Organization of the partnership

The consortium is composed of 17 partners, among which three national research institutions (CNRS, INRIA and CEA), and 14 High Education and Research Institutions (Université Grenoble Alpes, Université Paris-Saclay, IMT, Sorbonne Université, Université Claude Bernard Lyon 1, Université de Lille, Université Toulouse 3, CESI, ENAC, ENSAM, Université d'Evry, Université Gustave Eiffel, Université de Lorraine, Université de Strasbourg). Altogether, these partners and their research laboratories ensure the participation of researchers across the different research fields required to successfully address the challenges of this project: social and management scientists, psychologists, ergonomists, and computer scientists (human-computer interaction, software engineering, computer graphics, network and multimedia, virtual/augmented reality).

The project will be coordinated by the three coordinators (J-M. Burkhardt, C. Sandor, and M. Serrano) along with a fourth coordinator (M. Marchal). The four coordinators are complementary, as they are scientists in the different research areas required for this project.
The coordinators will also deal with administrative aspects and ensure the link with the rest of the PEPR program. Each axis of the project will be coordinated by a pair of coordinators:

- Axis 1: Maud Marchal and Marcos Serrano
- Axis 2: Jean-Marie Burkhardt and Christian Sandor
- Axis 3: Christian Sandor and Marcos Serrano
- Axis 4: Jean-Marie Burkhardt and Maud Marchal

3.3. Management framework

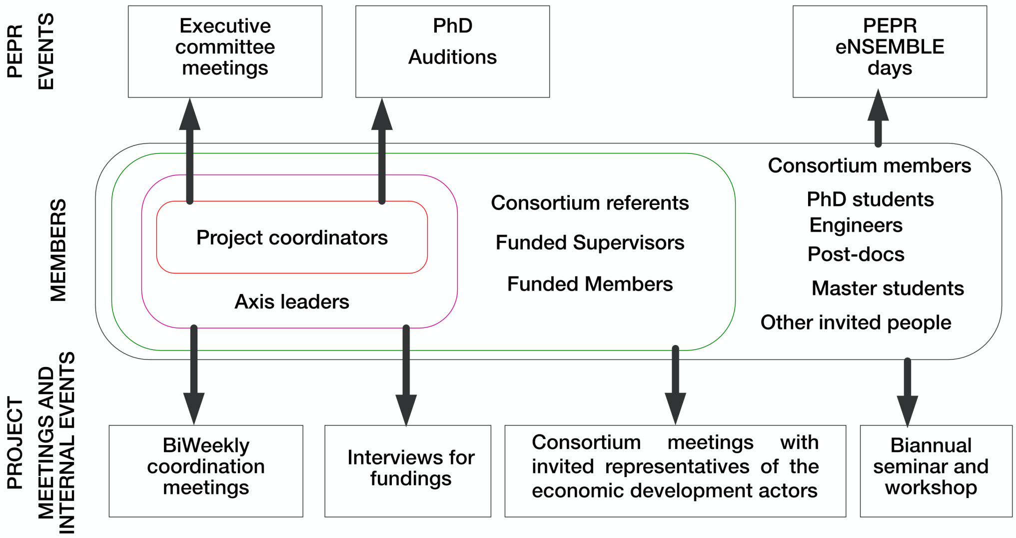
Allocation of Positions

During the course of this project, approximately 20 PhD and 20 internship stipends will be given out through open calls. The process will be identical to the other focused projects of the eNSEMBLE program.

For the allocation of postdoc (6 person years) and research engineer positions (8 person years), we will follow a hybrid model: a part will be allocated through open calls, and a part will be allocated directly by the axis leaders. The motivation for the direct allocation of positions is to ensure that the outputs of the PhD students can be polished and integrated with each other. Furthermore, as the project is distributed over the whole of France, it is necessary to allocate positions based on a geographical hierarchy, where several hubs are established to focus on the integration of results that are in closer vicinity. As principal locations, we envision Paris, Toulouse, and Rennes, as these coincide with the locations of coordinators.

Project management procedure

The project management considers both the partners role and the interlink with the other PEPRs focused projects. The partners will have different roles in the management according to their duties as project coordinators, axis leaders, consortium referents, funded supervisors of non-permanent recruitees or funded members.



To coordinate the project, there will be regular videoconference coordination meetings between project coordinators and axis leaders. These meetings can take place weekly at least at the beginning of the project, and biweekly later. These meetings will discuss the coordination, communication, research strategy and priority themes for PhD calls.

For each axis, there will be Axis consortium meetings with the previous partners (coordinators and axis leaders) and the consortium referents, funded supervisors and funded members. These meetings will allow project coordinators and axis leaders to follow the progress of all funded researchers. During these meetings, representatives from the relevant industrial ecosystem and from civil society (companies, clusters of companies, company incubators, partnership-based research institutes, civic organizations) will be regularly invited.

All the participants involved in the focused project will be invited to a bi-annual seminar and workshop (i.e. every 6 months): one videoconference and one physical meeting. These meetings will be mandatory for all funded members, who will present their work. These events will combine presentations and brainstorming sessions which will discuss the research topics to explore in the following years to better inform the priority PhD themes. We will also use these seminars to announce the upcoming fundings (master, post-doc, engineer).

Link with the rest of the PEPR program: The project coordinators will make the link with the other PEPR projects, through their participation in the PEPR Executive Committee, and in the evaluation of the PEPR PhD candidates. The project coordinators will decide whether a program-level engineer is needed to capitalize on the project results within the eNSEMBLE platform, and will report to the program governance level the national and international exchange needs of the project. All project members will be invited to attend the annual PEPR eNSEMBLE days.

Risk management

We have identified the potential risks and listed the corrective measures in the following table.

Risk Type	Risk	Corrective measure
Human Resources	PhD recruitment: we do not get enough candidates for all positions	Flexibility in the number of PhDs per year
Coordination	Works of different partners is not connected or integrated	Strong coordination in meetings. Integrative Postdocs/Research Engineers.
Technical risk	Networking problems between partners to make an interconnected prototype	Local demonstrator at Saclay, Toulouse and Rennes.
Technical risk	The technical setups, systems and devices become obsolete	Push for high level specifications As hardware is tied to PhD positions, we will progressively update.

Project resources, valorization of results and property share

The project will instantiate the necessary project management resources (instant messaging space, shared cloud, mailing lists), communication channels (project webpage, social network accounts, youtube channel). We will ensure that these are accessible to all partners.

We will also identify the communication referents of the different partners, to ensure that our communications can be appropriately relayed through their institutional communication channels and reach the largest possible audience.

Link with the general PEPR project management

The project coordinators take part in PEPR Executive Committee meetings. All the Milestones and KPIs will be communicated on due time to the PEPR pilots.

3.4. Institutional strategy

The partner institutions are major actors in research fields related to digital tools for collaboration such as Human-Computer Interaction, Augmented/Virtual/Mixed Reality, Psychology or Ergonomics. The partner institutions are historical and pioneering centers of Human-Computer Interaction in France and in Europe. They also provide skills through their LabEX, EquipEX+ CONTINUUM, AI institutes and scientific clusters essential for the CATS project.
Inria and the INS2I institute of CNRS are recognized for their scientific excellence in computer and digital sciences. Their strategies involve strong partnerships with French players in the field (telephony/communication, cloud, software publishers and digital services) and already collaborate closely through numerous joint research teams and national initiatives. The partner institutions support and promote interdisciplinarity which is at the center of human collaboration with digital tools.

4. Expected outcomes of the project

4.1. Expected scientific outcomes

The expected outcomes of the project are new understandings, approaches and tools to design and assess synchronous mediated collaborative situations and systems in hybrid and heterogeneous collaboration spaces. The deliverables associated to each of the four work-packages (cf. section 2.2) will extend beyond existing solutions to develop new components, systems and situations in order to enhance human collaboration, taking into account the diversity of users and their needs, the diversity of interaction devices/modalities for heterogeneous collaboration spaces, enabling the creation and access to complex hybrid collaboration environments and facilitating transitions between dynamic collaboration spaces. The progress of each of these four cutting-edge, interdisciplinary research axes will lead to incremental advances, but cumulatively they will lead to breakthrough collaborative spaces whose impact on changes in our daily collaborative activities will be identified and measured. This will result in a shift in collaboration spaces by creating a new generation of collaboration spaces that are capable of providing a sense of the presence of others even without physical proximity, awareness of the physical and digital contexts of other people, and ongoing awareness of activity. The ultimate goal is the creation of mixed physical and digital collaboration spaces in order to provide flexible multi-user experiences, adapted to the diversity and dynamicity of the interaction capabilities of each participant.
Socio-economic benefits are thus expected in the long term in a variety of domains that require collaborative work and joint-actions where physical contacts are partially undesirable or un-practicable, being it critical situations like a pandemic, or more routine work situations in distributed teams. The development of models, guidelines and interoperable components will ensure their rapid sharing within the research community as well as their use in companies, industries and by the citizens.
In addition, the project provides many opportunities to strengthen existing partnerships between the institutions involved in the PC1 CATS project, and more broadly in the PEPR, as well as to establish and develop other partnerships through links with field use cases and other relevant entities like major equipment programs, e.g., Equipex+ / Research Infrastructures CONTINUUM and Huma-Num, research programs, e.g., Acceleration PEPRs on Digital Education, on Digital Health and on Cybersecurity, and research networks, e.g., CNRS GDR “Internet, IA and Society”.

4.2. Dissemination strategy

The dissemination strategy is based on that of the eNSEMBLE program.
From a scientific point of view, we will ensure the publication and dissemination of results in major journals and conferences in the relevant fields (e.g., by supporting the organization of workshops associated with the main conferences in the fields).
We will follow ANR’s Open Science policy by requiring all funded research projects within the program to publish their data and outputs on national platforms: HAL open archive for publications, TGIR Huma-Num‘s Nakala for data. All the produced code will be released and maintained under open-source licenses and referenced in the Software Heritage database, with the support of the program's research engineers who will be specifically trained in these practices.
To ensure the visibility of the community beyond its scientific results, we will establish connections with national (AFIHM, AFIA, AFXR, ARPEGE) and international (ACM, EUSSET) learned societies, taking advantage of the fact that several Program Directors and members of the Executive Committee are strongly involved in them.
Regarding the general public, civil society and institutions, the Executive Committee will encourage the participation and presentation of the program's activities in annual national events such as Fête

de la Science, or in outreach initiatives in high schools such as Chiche!. They will also work closely with local initiatives of pilot and partner institutions to bring the academic world closer to society, such as contributing to funding programs for artists' or designers' residencies in research laboratories (e.g. AIRlab at University of Lille). This will feed our research, but also produce artifacts adapted to communication towards the general public (interactive artworks, serious games, performances) that will be showcased e.g., during public sessions of the eNSEMBLE days.
Starting in year 2, the Executive Committee will organize the annual eNSEMBLE days, that could include: “Innov’ eNSEMBLE”, a forum and exhibition of demonstrations targeting users, companies and institutional representatives, which will foster connections with these actors and more generally with civil society (this session will take place once enough demonstrators have been developed).

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