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Concepts of multimodal interactions to support Human Performance in Remote Tower Operations

Candidate
Rosa De Piano

Supervisors
Prof. Patrizia Marti
Dr. Luca Save

PhD Coordinator
Prof. Luigi Chisci

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Abstract

Context - This thesis deals with the development of exploratory concepts of multimodal interactions able to support the Human Performance (HP) of Tower (TWR) Air Traffic Controllers (ATCOs) from a remote tower, during the traffic management on the area under their responsibility.

Nowadays the TWR Controllers' job consists in the management of the aircraft and vehicles movements on the runways and taxiways of an airport and they perform their tasks with the Out-The-Window (OTW) view, which means that they look at the vehicles without using any screens, but directly looking outside of the tower building windows, especially in small and medium airports. In recent years, a new operational concept emerged in aviation: the Remote Tower Operations (RTOs). The motivation of the growth of this new concept is the current European situation of small and medium density airports that often have to face the difficulties and the high costs for the provision of a safe and efficient Air Traffic Service (ATS). Many of these airports act as public service routes for isolated communities and their importance is increasing with the expansion of low-cost airlines; for these reasons, in order to avoid the risk of closed down these airports and with the aim to maintain an adequate level of safety and efficiency, several European countries are in process of developing remote tower management for small and medium density airports. The idea behind is that in the new remote working environment, the Tower ATCO will no longer perform his/her tasks from a local aerodrome but from a distant position. According to the European guidelines that are being developed to define the technical and operational requirements of the Remote Tower system, it is supposed that the TWR ATCOs will monitor the traffic mainly through the implementation of high definition cameras, including also radar screens and radio transmission, instead of the OTW. In addition to the visual information, the aerodrome outdoor sound is also taken into consideration for the development of the Control Working Position (CWP) support tools, without any mention to data collected through other sensory modalities.

The PhD work has been carried out in the framework of a European project called MOTO (The embodied reMOte TOwer), which considering the above-mentioned context and the theories of multisensory interaction and embodied cognition, explores the possibility to improve human performance in RTOs.
The multisensory concept and the embodied cognition, which study the feeling and the modalities humans use to interact with the environment, have been considered as the theoretical context to achieve a full understanding on how controllers use all of their senses during every day operations, in order to improve the situation awareness and to decrease the workload. This approach offers the advantage of analysing complex human behaviours during natural interactions in real-world environments and in enriched simulations of the real world.

Approach and activities - In order to investigate the role of embodied cognition in TWR ATCO, and thus to explore the design of concepts of multimodal technologies for Remote Tower Operations, a design process have been carried out as the main activity of this thesis.
Starting from the embodied cognition and the multisensory integration, the approach of the activity on the concepts design analyses how the development of multimodal solutions, able to support the Human Performance in the Remote Tower Operations, can lead to the elicitation of new operational and user's needs. With regard to the approach used for the purpose of the design process, it has been adopted and adapted the co-evolutionary design methodology, which is structured in three main phases: problem setting, concept generation and concept development. According to this approach, the concepts generation, the user research and the technology selection should be carried out in parallel, so that each step of the process can provide inputs and enrich the others:

1. **Problem setting**: in this first step, inputs on technologies and/or evocative ideas on multisensory interactions and integration have been collected from multiple domains, enriched by the review of the ATM literature and by a small human-in-the-loop experimental exercise aiming to identify the target users, their needs and

some examples of future scenarios of RTOs.

2. **Concept Generation**: during this phase, the first inputs on multimodal interactions have been analysed and included in the context of Remote Tower Operations, with more details on RTOs with respect to the problem setting. The results were a first set of graphic visualisations of the multisensory integrations that have been produced with the support of two illustration and graphic design experts.
3. **Concept Development**: in this phase the draft version of the multimodal technology concepts developed in the previous steps, have been finalised with the support of an Air Traffic Controllers, who gave their support in developing coherent Remote Tower scenarios where the suggested multimodal interactions could be explored and deepened with additional design research activities.

During the initial steps of the design, the main activities on concept design, user research, technology and strategy insights worked autonomously but they also ran in parallel, with the aim to explore the boundaries of the design space from different perspectives.

The work on the concepts has been considered as one of the inputs for the MOTO project, in particular with regard to the phase of concepts design in the context of further tests in Remote Tower Operations.

Document structure and contents - This thesis is composed of six different chapters, completed by four appendixes, the bibliography, the webliography and the list of publications done during the PhD.

- Chapter 1 introduces the context of the work done during the PhD research and it describes the correlation between the research domain, the scopes and activities of the European project MOTO, and the PhD research questions, objectives and activities;
- Chapter 2 gives a detailed overview of the embodied cognition theories and of the multisensory integration concept, together which references to the

multimodality in the ATM domain. This chapter constitutes the theoretical framework of the PhD study and of the MOTO project and it is fundamental to understand the multimodal integration which is explored with the two activities described in chapter 4 and 5;

- Chapter 3 provides a brief introduction to the current Control Tower Operations and a more detailed description of the Remote Tower Control concept, with a specific attention on the Controller Working environment, on the roles, responsibilities involved in the new concept, together with a description of the tools and systems the operators use to perform her/his tasks;
- Chapter 4 focuses on the main strand of activities, carried out to develop the exploratory design of multimodal interactions concepts for future scenarios of Remote Tower Operations, as well as the description of the design approach, the activities performed and the results achieved at the end of the design process;
- Chapter 5 summarizes the contribution of the thesis and it discusses avenues for future research;
- Appendix A reports the template of the interview done with Air Traffic Controllers during the process of the scenarios definition;
- Appendix B includes the preliminary set of control tower operations that have been developed during the first phase of the design process, the problem setting, and which have been further improved to achieve the final scenarios reported in Chapter 4;
- Appendix C contains the Task Analysis review that have been used for the analysis of the activities performed in the tower control operations and that have been taken into consideration for the definition of the scenarios for the future RTOs;
- Appendix D reports the questionnaires used to measure SA, workload and performance (SME questionnaire) that represent supplementary worksheets for the reading of the experimental exercise reported in Chapter 4.

- Bibliography and webliography contain the list of paper, books, web pages, journal articles consulted during the study;
- Publications lists the papers, posters and abstracts prepared for International conferences.

Chapter 1

The embodied reMOte TOwer

1. Context of the research

The three-year research of the PhD has been performed in the framework of the European project MOTO (the embodied re**MO**te **TO**wer) funded by SESAR Joint Undertaking (SJU), the European public-private partnership which manages all Research and Development (R&D) activities in the field of Air Traffic Management (ATM) in Europe. The work done in the PhD has been influenced by other parallel activities performed inside several European projects at Deep Blue srl, where the doctoral research has been carried out along the last three years. The involvement in these projects contributed to the acquisition and to the improvement of crucial theoretical and practical skills for the planning, the development and the execution of the activities included in the design process, especially for the phases involving the end-users. Thanks to the participation in the European projects, there was the possibility to:

- explore the aviation domain;
- improve the knowledge on Human Performance (HP) aspects, their interaction with the working environment and the systems in use;
- enrich the expertise on the HP assessment methodologies and techniques; and to carry out activities with the target users (e.g. focus group, workshops and simulation sessions).

The projects and the related activities that contributed to the construction of the theoretical and operational framework behind the PhD thesis are reported in the following table:

Title	Description	Activities
FAROS[1]	FAROS is a project of the maritime	Collection of both quantitative (e.g.

[1] Project included in the Seventh Framework Programme for Research and Technological Development (FP7), created

Human Factors in Risk-Based Ship Design Methodology	sector and it dealt with finding out whether the design of different types of work space can have negative effects on safety and human performance, in terms of errors committed by the person involved. The project activity that contributed to this thesis was the experimental exercise. The exercise aimed to understand how to improve the working space design and which factors have an impact on the Human Performance during the interaction with the working environment and the tools involved in the operators' everyday tasks. The subjects were seafarers working for the Estonian passenger and cargo shipping company Tallink.	timing, ratio between the number of errors and correctly performed tasks) and qualitative data (i.e. brainstorming at the end of the exercise) on the subjects' performance during the experimental exercise in the simulated VR environment, reproducing the inside of a ship working space.
PROuD[2] *PBN Rotorcraft Operations under Demonstration*	The project objective was to assess the introduction of new instrumental procedures specifically developed for Search and Rescue (S&R) helicopters, in areas characterized by adverse weather and orographic conditions that do not give the possibility to execute Search and Rescue operations. The new procedures have been tested during demonstration flights performed by the Rega pilots (one of the project partners), who operate in the Engadin valley in Switzerland, specifically in Samedan and Chur, and during demonstration flights executed by another partner of the project, the pilots of NLA, who provide the same service in Norway in the areas of Lørenskog and Ullevål.	Data collection and analysis through the use of ad-hoc questionnaires, which aimed to evaluate the subjects' perception of the following indicators: • situation awareness; • workload; • safety; • accessibility and availability; • efficiency; • predictability; • Human Performance (operating methods, errors and system degradation). Editing of the final results report, produced with the contribution of the other researchers and project' partners.
ACROSS[3] *Advanced Cockpit for Reduction of*	The scope of the project was to analyse and assess the impact of new technologies introduction in the aircraft cockpit, in order to measure	"Over-the-shoulder" observations to monitor pilots' level of workload and stress during long-term flight in a

by the European Union to finance the research in Europe. (http://ec.europa.eu/research/fp7/index_en.cfm).

[2] European project co-financed by SESAR Joint Undertaking (SJU), which had duration of two years (October 2014 – October 2016).

[3] The project had duration of three years (January 2013 – June 2016) and it was included in the FP7 program of the European Commission.

Stress and Workload	the civil aviation pilot's performance in situation of high level of workload and stress. During the project multiple solutions with different level of maturity have been developed and tested in experimental exercises in which the data collection has been carried out with different methodologies as questionnaires, interviews, focus group, walkthrough and quantitative techniques.	simulated cockpit environment. Focus group activities performed with the civil aviation pilots and the HF experts at the end of the experimental session. Editing of the final results report, produced with the contribution of the other researchers and project' partners.
DARWIN[4]	The project aims to create a set of resilience guidelines intended for the manager of critical infrastructures (e.g. the Italian National Institute of Health), air navigation service providers (e.g. the Italian company ENAV S.p.A.), and national entities involved in the emergencies management (e.g. police, firefighters and civil protection departments). The guidelines that are being developed could provide an efficient and easy-to-consult tool during critical operations.	Participation in the workshop with the end-users, held at the Italian National Institute of Health in Rome, during which the participants (both aviation and health domains experts) and the partners' project have been involved to collect information on the contents and the formats of existing guidelines in the aviation and health domain. Collaboration to the definition of emergency and critical events scenarios involving managers of the aviation and health domains. The objective of this activity was to analyse the interaction modalities among the actors of the scenarios and the procedures they apply to deal with the emergency.

Besides the projects included in the above table, the MOTO project has been the one with more direct and tight relations with the thesis. Some of the thesis activities (i.e. those related to the experimental exercise) have been carried out during the project lifecycle, while others (i.e. those referring to the design process) have been performed independently from the project (but in parallel) and could be used as a starting point for further project's tasks. The interconnection between the PhD study and MOTO is further detailed in chapter 1.2.

The domain of the MOTO project and, thus, of the PhD work is the Air Traffic Management (ATM); specifically, the Remote Tower Control service, an emerging new

[4] The project is included in the project of *Horizon 2020* and started in June 2016.

“operational concept that enables the cost effective provision of Air Traffic Services (ATS) at one or more airports from a control facility that is not located in the local ATS Tower” (OFA 2013: 1). The Air Traffic Service (ATS) is a generic term that refers to three kinds of service which is provided to the airspace users for a safe and efficient flight: Flight Information Service (FIS), Alerting Service (ALRS) and Air Traffic Control Service (ATC).

Nowadays the Tower Control service is performed locally by the Tower Air Traffic Controllers (TWR ATCOs), who manage the traffic from the Control Tower building, physically located in the vicinity of the runway(s) under their responsibility. The area managed by the Tower ATCOs is called Aerodrome Traffic Zone (ATZ) and it consists of the manoeuvring area, which includes the runway(s), the related taxiway(s) and the airspace around the airport within a range of 8 kilometres and up to 700 metres of altitude. With the introduction of the Remote Tower System, the main change foreseen from the current modality of tower control to the new operational concept is that the Tower ATCO will not perform his/her tasks from a local aerodrome but from a distant position. In chapter 2.3 it is provided a more detailed description of the Tower Control service and of the Tower ATCOs' tasks.

In Europe there are several small and medium density airports that provide public service for isolated locations and they have a great importance for the communities of those areas. These airports risk to be closed due to the difficulties and to the high costs to provide a performative Air Traffic Service (ATS). In order to avoid this possibility, in many European countries it is being developed the remote tower management for small and medium density airports.

According to the European guidelines that are being developed to define the technical and operational requirements of the Remote Tower system (see OSED 2015), it is supposed that the TWR ATCOs will monitor the traffic mainly through the implementation of high definition cameras, including also radar screens and radio transmission. The operator would control the area by looking at screens where the situation is displayed in a similar way as what s/he could see “out of the window” in current tower building on the airport. In this regard, the SESAR document on Operational Services and Environmental Description (OSED), which describes the concept of Remote and Virtual Tower, providing also guidelines for the characteristics of the operational environment and of the working methods and interaction, states that:

> *"The visual observation will be provided by visual information capture via cameras and/or other sensors. This will provide operators with a view of their area of responsibility in line with regulatory requirements." (OSED 2015: 36)*

It is also supposed that the information gathered through the visual channel will support the process of decision making of the ATCOs, without any mention of data collected through other sensory channels.

> *"Just as in traditional operations where the direct view from the tower underlies different conditions, the ATCO in the Remote Tower Module will take a decision based on what information the visual representation provides in each case." (OSED 2015: 36)*

> *"The visual presentation may be overlaid with additional information pertinent to the general area of interest or area of responsibility, in order to increase ATCO/AFISO situation awareness. The fundamental classes of information that may be incorporated into visual presentation overlays include: geographic, meteorological, operations and service and visual reminder information." (OSED 2015: 43)*

As anticipated, in addition to the visual information, the aerodrome outdoor sound is also taken into consideration for the development of the Control Working Position (CWP)[5] in particular for the rendering of engine and ambient noises, for instance the wind noise, with the suggestion to relay the audio into the remote facility via speaker, if necessary. Moreover it is added that:

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[5] The operator (ATCO / AFISO) work station including necessary ATS systems

"If a function for actual outdoor sound reproduction is implemented [...] the sound shall be linked in a directional manner with the visual presentation of the aerodromes." (OSED 2015: 129)

The reproduction of the outdoor sound is supposed to be managed paying attention to the characteristics of the Control Tower and giving the ATCOs the possibility to control the sound volume. Here below, a fragment of the OSED clarifies the above-mentioned idea.

"To further improve ATCO/AFISO situational awareness the aerodrome's background sounds may be captured and relayed. This is likely to be dependent on the size of the aerodrome, as in current operations the local towers of large aerodromes are often sound insulated due to the amount of background noise. In smaller towers however aerodrome sound may aid situational awareness and even detection of occurrences. The benefit of a remote tower implementation is that aerodrome sound may be volume controlled and switched on or off as required." (OSED 2015: 44)

Besides the presentation of visual and auditory information, additional references are introduced with regard to sensors (without any specific technical requirements, at least until now), which could be implemented to provide other kind of information or to integrate data to the visual channel.

"Various sensors will also be required in order to provide the remote operator with all the information they would normal have access to if providing ATS locally under current operating methods." (OSED 2015: 36)

"The visual presentation may source information from a variety of sensors including visual range cameras, infrared cameras or other sensors. Additionally the primary form of visual surveillance may be enhanced with information received from secondary sensors (again in the visual and non-visual ranges), these secondary sensors may be used in order to provide enhanced information to operators on secondary or integrated visual presentations or as overlays. This

could include computer based virtual information for use in virtual tower installations." (OSED 2015: 36)

The above-mentioned citations are in line with the Human Performance research in Remote Tower Control which is mainly focused on two senses: sight and hearing, while the other sensory channels, especially touch, are less explored; in fact the efforts and resources are being invested especially on the development of visual technologies prototypes, which will enhance the human vision, for instance with the implementation of overlaid information on the visual channel.

The panorama introduced does not consider the experience of the operator from a perspective of multisensory integration with the operational environment.

A multisensory integration foresees the involvement of the human physical perception while acting in the world, and the influence of cognitive and body perception when collecting information and taking decision on the world around us. It is also known as "multimodal integration" and it is the study of how information from the different sensory modalities, such as sight, sound, touch, smell, self-motion and taste, may be integrated by the nervous system. In addition, multimodal integration also deals with the modalities in which stimuli from different sensory channels interact between each other.

The advantages of combining multiple sensory modalities are a coherent representation of objects and meaningful perceptual experiences of the environment we are immersed in everyday life.

Coming back to the research in RTOs domain, the restricted focus on visual technologies prototypes does not give the opportunity and the challenge to exploit other senses, in order to reproduce a more realistic perception of the reality. Moreover, the exclusive exploration of the visual channel may lead to information overloaded for the air traffic controllers. The direct access to the world through the human senses is crucial for the operator's performance in tower control setting especially in small insulated airport where the environmental sound and vibration add information to the visual channel.

1.1 The MOTO project

Taking into considerations the context of the research (chapter 1), the idea behind the MOTO project and the PhD research is that the Remote Tower system and the operator's interaction can be enhanced by considering human performance in control towers from the perspective of the multisensory integration and of the embodied cognition, with the goal of supporting the human-system interaction with multimodal technologies. The proposal is to apply the Embodied cognition framework to understand controllers' perception and actions in a Remote Tower setting, to explore if the embodiment plays a role in everyday performance and how to make a Remote Tower Operations as real as reality, in order not to negatively impact on Air Traffic Controllers' tasks, in particular on their situation awareness, workload, on the safety and capability in general.

ICAO defines Human Performance (HP) as "the human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations" (ICAO 2017) and an effective HP is crucial for the operational safety in aviation. This concept has become commonly known as Human Factors (HF) and it refers to all the "many aspects of human performance which interact with their (aviation) environment to influence the outcome of events. These may be related to either the physiological or psychological aspects of human capability, both of which are able to directly affect the way in which the human operator performs in different circumstances" (Skybrary 2017). The concept deals with aspects related to the operators' performance and his/her relation with the working environment and conditions that could be explored and studied to improve the overall structure of safety-critical activities, as those carried out in the aviation context. The high safety standards required in this domain led to a wide exploration and application of the HF theories and practices.

Several undesired situations may occur during the interaction between the operator, complex procedures and systems' interfaces that are implemented in the operators working position to support him/her in the safe execution of his/her tasks. Sometimes it may occur that unintended errors happen during the operators' duties and "The context for these errors may be simple lapses in the behaviour of well-informed professionals or it may follow from an underlying failure to appreciate the full range of behavioural influences or their potential consequences." (Skybrary 2017). There are different typologies of errors and they also vary based on the degrees of severity and on the potential results they could produce. The operators' performance can be negatively impacted by inappropriate and/or inefficient procedures in an organisational complex framework. The research on Human Factors aims to minimize errors supporting the actors involved in this complex network, improving the interaction with the technical systems, the cooperation with other roles involved in their work flow. The study on error reduction and error management brought also a bigger awareness of the Human Factors impact in all the aspects of the operators' performance, especially in the design of new systems and in the strategies to mitigate undesirable effects to preserve the safety of the operations. In addition efforts from the aviation communities are being done to highlight the importance of a broadly consideration of HF in order to proactively intervene on the decreasing of the accident rate.

Taking into consideration the context of the MOTO project, the theoretical background and the HF concept in aviation, the research questions behind the MOTO project are the following:

1. Are current Remote Tower technologies losing crucial elements, with regard to the reproduction of realistic human perception?
2. What is the role of Embodied Cognition in human performance in control tower operations?

In order to answer to the above-mentioned research questions, the project established an overall objective, which gave raise to four sub-objectives. The main one is to identify the key multimodal stimuli required on Remote Tower Operations to improve the sense of presence experienced by ATCOs.

This objective is expected to lead to the achievement of the enhancement of human performance, by exploiting multisensory stimuli, including but not limited to the already overloaded visual channel, but without increasing the ATCO workload and decreasing the situation awareness, due to the stimuli increase. The research opportunities that the MOTO project aimed to catch are mainly two:

1. Exploration and definition of the role and the use of all the human senses in tower operations with the acquisition of an embodied cognition approach;
2. Design efficient and feasible multimodal solutions with a rethinking of the traditional human-system interaction model.

During the two years of work in the MOTO project, four sub-objectives must be reached to obtain valid results able to support the research questions and hypotheses of the MOTO project. The sub-objectives are related to different activities planned in the project and all of them compose the path to the main end scope. Here below the four sub-objectives are reported, while the project activities are described in the next chapter.

- **Objective 1:** Explore and test the role of multimodal acquisition of information in current control tower operations;
- **Objective 2**: Identification and definition of user requirements for a multimodal Remote Tower, with the aim to reproduce multimodal perception in a remote tower simulation platform;
- **Objective 3:** Development of brain-physiological indexes, adapted to operations in Remote Towers, in order to be able to monitor aspects of HP like workload and situation awareness;
- **Objective 4:** Perform experimental sessions to assess the results of objectives 2 and 3 in realistic ATM operational conditions through two environments. The first one composed of a Virtual Reality setting in which the current tower operations are simulated; the second one represented by a realistic Remote Tower platform where to assess the implementation of multimodal technologies in control tower tasks.

[redacted]The MOTO activities

The project has duration of two years and involved four partners: Deep Blue and

University of Sapienza from Italy, l'École Nationale de l'Aviation Civile (ENAC) from France and the University of Groninghen from The Netherlands. The partners share the responsibility on the activities planned in the projects; activities that are defined in a set of tasks and are grouped in work packages. Each Work Package (WP) foresees both the execution of the related tasks and the production of reports on the activities progress.

WP1 – Baseline and gap analysis: The aim of this WP was to record multisensory information (visual, auditory and haptic) interesting the real tower settings; in particular the video of the ATZ under Tower ATCOs control, the sound of the external environment and of the vehicles (aircraft and vehicles on ground), the vibration coming to the tower building, as for example those produced by the wind. These measurements have been used to reproduce a realistic tower control environment in Virtual Reality (VR) that constituted the experimental set-up for the experimental sessions carried on in the WP4. The results of WP1 are:

- A set of scenarios describing everyday situations of Tower Operations;
- User and technical requirements for the reconstruction of the realistic multisensory remote tower platforms in Virtual and Augmented Reality (AR);
- Structured design space of available multisensory information and their potential usages as interaction modality, both in Virtual and in Augmented Reality.

WP2 – Enhancing embodiment: This WP aimed at the development of a set of technological solutions to be used in a remote tower platform, in order to reproduce a realistic tower. The settings that have been and will be used as remote tower are a VR environment, where the control modalities currently used by the ATCOs have been simulated; a second setting, which will consists of a Remote Tower platform, where selected technological solutions will be tested to understand their realism in an operational setting of Remote Tower Operations.
The expected results of this WP are:

- Data collection and analysis to assess if the Virtual Environment can reproduce a multisensory control tower;
- Technology requirements for the development of multimodal remote tower platforms.

The activities in this WP helped to understand if and how the ATCOs use the multisensory integration during tower operations.

WP3 – The augmented remote tower: This WP will explore the technological possibilities to improve human performance from a multisensory perspective. To this WP is related the activity of the PhD study on the concepts design that is detailed in 5.3. The multimodal solutions developed with the WP3 activities will be implemented in a prototype of Remote Tower Platform and their feasibility in the Remote Tower control will be assessed.

The expected results from this WP are:

- A set of multimodal solutions to decrease the workload and increase situation awareness.
- User requirements for the development of an Augmented Remote Tower setting where the ATCOs can operate with a multimodal interaction.

WP4 – Validation: The activities of this WP aimed to the planning and to the execution of experimental sessions in different settings, aiming at assessing the results obtained from the activities in WP2 and WP3. In particular a first set of validation exercises have been performed to assess the role of embodied cognition in the VR setting, where the traditional tower control operations have been reproduced. A second cluster of validation exercises will be carried on in an Augmented Remote Tower platform, where the multimodal interaction will be assessed.

The expected end results include:

- Feedback from the first validation exercise on user's performance in terms of situation awareness, workload and sense of presence;

- Feedback from the second validation sessions on user requirements for augmented multisensory interfaces in remote tower platforms.

The following image gives an overview of the workflow and relations among the different work-packages of the project.

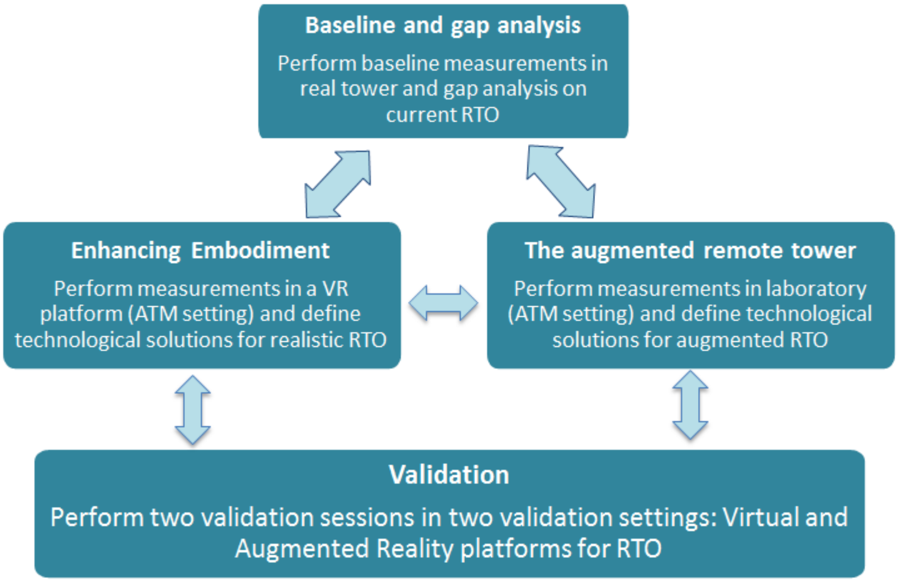

Figure 1 – Interdependence of WPs activities (adapted from the MOTO project)

The table below maps the relation between the activities of the Work Packages (WPs) represented in the figure above and the objectives of the project, already mentioned in the previous chapter.

On the left hand the objectives of the project are listed and on the right column a set of associated activities are showed. As the table highlight, the objectives are not in a unilateral relation with the activities of the Work Packages but they are transversal to more than one WP, because the achievement of a specific objective needed the combination of multiple activities. It is the case of the objective 1, for example, that refers to activities performed inside the WP 1 (literature review, interviews with ATCOs, design and definition of scenarios, workshop with ATCOs, baseline measurements) and the WP4 (first validation session); objective 2 is associated to WP1 (literature review, gap analysis, baseline measurements), WP2 (state-of-the-art) and WP4 (first and second validation sessions).

Table 1- MOTO objectives and activities

Objective	Associated activities
Obj 1: To assess the role of sense of presence/immersion in control tower operations	Literature review (WP1) Interviews with ATCOs (WP1) Design and definition of scenarios (WP1) Workshop with ATCOs (WP1) Baseline measurements (WP1) First validation session (WP4)
Obj 2: To define user requirements for a multimodal Remote Tower.	Literature review (WP1) State-of-the-Art (WP2) Gap analysis (WP1) Baseline measurements (WP1) First validation session (WP4) Second validation session (WP4)
Obj 3: To define brain-physiological indexes, customized for Remote Tower operations	First validation session (WP4) Second validation session (WP4)
Obj 4: Validate the above results in realistic ATM operational conditions through simulation facilities.	First validation session (WP4) Second validation session (WP4)

1.2 The PhD study

As explained in chapter 1.1, there is a wide overlap between the PhD research and the activities of the MOTO project. However, this overlap is only partial; it can be placed between two of the main MOTO research opportunities highlighted in chapter 1.1:

1. Exploration and definition of the role and the use of all the human senses in tower operations with the acquisition of an embodied cognition approach;

2. Design efficient and feasible multimodal solutions with a rethinking of the traditional human-system interaction model.

In fact, starting from the embodied cognition and multisensory integration role in Tower Operations (point 1), the aim of the PhD thesis was to explore the multimodal concepts design and to identify design proposals for the development of efficient and coherent multimodal solutions prototypes for Remote Tower Operations (point 2).

The motivation of the PhD research is the interest in the exploration of Human Performance in complex system, which involves multiple layers of activities and different roles and responsibilities aiming at the equilibrium of the whole system. The aviation domain is a wide and fertile field for the analysis of complex interdependencies and relationships, where actors with varied expertise and tasks have to collaborate on different levels, in order to guarantee a high level of efficiency and safety of the network they are actively involved in.

The MOTO project offered the opportunity to observe and analyse the Human Performance in a new simulated operational environment where the traditional idea of Tower Control will mostly change with the transition from the Out-the-Window view to the remote configuration. The impact and the consequences of this concept on Air Traffic Controllers' performance was one of the starting points for the research. In order to identify the burden of the impact and to support the ATCOs in everyday tasks, it was fundamental to gain a deep knowledge of the RTOs concept and of the research path that is being undertaken at international level. It has been noted that the wider tendency in the RTOs projects is mainly the development of visual technologies, as already introduced in chapter 1.1. The tendency can be also motivated by the traditional approach to human information processing in Human Performance on ATM in general, which still consider human cognition as composed of input acquisition-processing-action phases and that they are clearly and definitely separated. The Embodied Cognition research, instead, has demonstrated how these phases are much more interconnected than previously known.

Thanks to the activities performed inside the MOTO project, it was possible to explore new technological possibilities with the introduction of the embodiment approach and the multisensory integration as enablers of ATCOs performance. One key concept of the multisensory integration is that it could provide the opportunity to explore the Human Performance, to create more efficient and natural interaction and to avoid a negative impact on the operator's performance. The more integrated the setting, the easier it is for humans to rely on natural processes of dynamic attention and action in the environment. The study of Sklar and Sarter, which analysed the implementation of haptic feedback during interaction mechanisms, demonstrated that through haptic feedback pilots could better monitor mode changes and intervene on the unforeseen ones.

> "*Sklar and Sarter (1999) therefore employed the tactile modality for notifying pilots of mode changes and compared this approach to current and enhanced visual cues in the context of a realistic flight simulation flown by flight instructors. The results were remarkable; with tactile cueing, pilots detected all of the unexpected mode transitions even as the workload and attentional demands of other flight tasks increased. In contrast, with visual cues, performance was never perfect and dropped off significantly as workload increased. [...] with tactile cueing, pilots became aware, in one sense of the term, of all indirect mode transitions, but when these transitions were expected, the cue did not interrupt or interfere with ongoing tasks. Only when the cue signalled an unexpected mode change did pilots follow up overtly*" (Wood and Sarter 2010: 16)

Aviation studies, like that of Sklar and Sarter's, provide references to the overall idea of the exploration of multimodal interaction where the auditory and vibrotactile feedback can support the operator's tasks. This does not mean that the visual input has not been considered at all but it has been taken into account, especially when integrated with other sensory modalities.

Once applied the approach of the multisensory integration, another key question is the kind and the amount of information that could be provided from a different sensory channel instead/or in addition to the visual one. This was one of the design questions to answer when developing the concepts of new technological solutions, in particular during the phase of concept generation when the first draft of a set of multimodal interactions have been prepared. Another key point was understanding of how the integration of multiple sensory stimuli could have been organised and which relation the different channels establish between each other, while sending a specific message to the ATCOs. These questions have been explored with the aim to answer with an efficient, coherent and naturalistic interaction experience in RTOs.

In addition to the aviation studies and to the design questions, some statements, in the form of suggestions and observations on ATCOs reliance on multisensory information have been used as operators' evidences of the multisensory role in their everyday duties. In control towers, controllers described situations in which they rely on vibrations, sound distance and speed (of the wind for example) to take their decisions.

1.2.1 Research questions

All the above-mentioned considerations led to the formulation of the research questions to which the PhD work aimed to answer. Part of these questions overlap with the research path of the MOTO project, while others are independent from them. As stated in chapter 1, MOTO research questions are:

1. Are current Remote Tower technologies losing crucial elements, with regard to the reproduction of realistic human perception?
2. What is the role of Embodied Cognition in human performance in control tower operations?

Starting from these questions, PhD posed the following ones:

1 Is there any impact of multisensory integration on ATCOs' performance in control tower operations?
   - 1.1 If yes, what kind of impact is there, specifically with regard to situation awareness and workload?
   - 1.2 What kind of suggestions for the design of multimodal solutions can be

provided to support ATCOs' performance in Remote Tower Operations?

In summary, the PhD objective is to carry out an exploratory design process to define multimodal interaction concepts for Remote Tower Operations, generating recommendations and proposals on how to design multimodal interaction features in RTOs environment. For the purpose of this research, the deepen study of the role of human senses and of their impact on routine operational situations was a starting point to explore the design of credible, realistic and efficient interactions between the human, the tools and the procedures. The end goal of an effective design is to maintain an acceptable level of safety of the operations and the protection from error occurrences, through the improvement of the human performance.

The multimodal interactions are expected to support controllers to enhance their level of attention and to facilitate the transition between the direct management of the traffic of one airport from a local tower building, to a remote configuration of the Controller Working Position, both in single and multiple RTOs.

1.2.2 Approach and activities

> *"Design research is in a state of flux. The design research landscape has been the focus of a tremendous amount of exploration and growth over the past five to 10 years. It is currently a jumble of approaches that, while competing as well as complementary, nonetheless share a common goal: to drive, inspire, and inform the design development process. Conflict and confusion within the design research space are evident in the turf battles between researchers and designers. Online communities reveal the philosophical differences between the applied psychologists and the applied anthropologists, as well as the general discontent at the borders between disciplines. At the same time, collaboration is evident in the sharing of ideas, tools, methods, and resources in online design research communities."* (Sanders 2008: 13)

These are the opening words of Liz Sanders' article "An Evolving Map of Design Practice and Design Research", which deals with the state of design research and the development of a design research map in order to clarify the interconnections between the multiple approaches, tools and methods shared inside the research design communities. As Sanders states "[...] the underlying landscape of the map may be relatively permanent, changing only as major forces affect it. But the tools and methods shift and change somewhat like trends" (2008: 13). The flexibility of the map gave the possibility to use it as a framework to arrange the approach and the methods used and the activities performed during the PhD work.

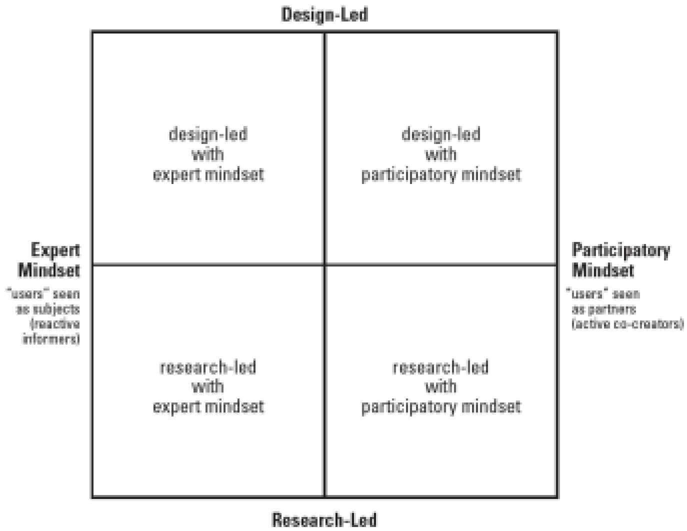

Figure 2 - Map of Design Research - Underlying Dimensions (Sanders 2008: 14)

The map is organised around two intersecting axes: i) *approach,* which includes two opposite sides: design-led and research-led perspective, with the second one having its roots in anthropology, sociology, applied psychology and engineering; ii) *mind-set*, which encompasses the expert and the participatory mind-set dimensions. The former is characterised by designing *for* people, who are considered as users, more passive subjects and/or also consumers. The latter (participatory mind-set) refers to a culture that considers people more as co-creators and domain experts instead of passive subjects; the design researchers located in this axe of the map aim to design process/product/service *with* people, who are actively involved from the early stages of the design process.

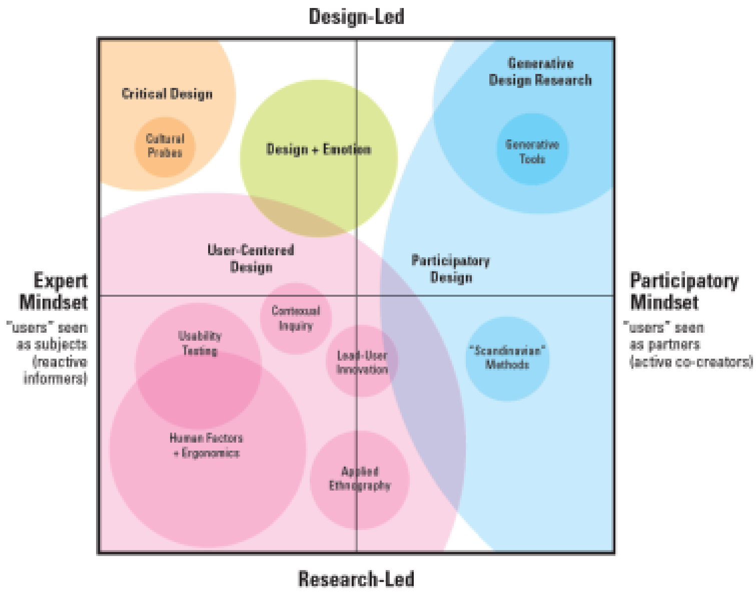

Figure 3 - Map of Design Research - Research Types (Sanders 2008: 14)

The design areas identified by the author are five: i) critical design; ii) design and emotion; iii) generative design research; iv) participatory design; and v) user-centered design.

Critical design is applied by expert mind-set designers who analyse the status of a specific context, case and/or situation and then let people critically think on the current values people have and/or share. In order to do that, the methodology used is cultural probes: "ambiguous stimuli" (Sanders 2008: 15) which are collected as inspiration for the design process and whose aims is to produce a reaction into the users' mind.

Design and emotion is driven by the design-led and research-led approaches but with a focus more on the design-led area. This kind of design "raises issues and facilitates dialogue among practitioners, researchers and industry in order to integrate salient themes of emotional experience into the design profession." (www. designandemotion.org: 22nd February 2018). It has been created also a Design &

Emotion society in 1999 that put together researchers, designers and companies interested in exchanging ideas, insights, research methods and tools able to involve the users in the knowledge sharing experience that characterises the design and emotion mission.

In the design-led approach and participatory mind-set at the opposite side, there is the **generative design** that aims to support and encourage people to develop alternative ideas and insights to a specific situation or context. The instrument used is the “generative tools”, a sort of design language that designers and users share as way to communicate among each other. It is defined *generative* “in the sense that with it, people can express an infinite number of ideas through a limited set of stimulus items.” (Sanders 2008: 15)

The **participatory design** approach, which is located between the design-led and research-led areas on the right side of the map, is characterised by the involvement of the end-users from the beginning of the design process, in order to help the designers to develop services and/or products that satisfy the users’ needs. The participatory design methodology foresees the use of physical tools that enable the process of thinking and sharing ideas among the people involved along the process.

The **user-centred design** has the scope to “collect, analyse and interpret data in order to develop specifications or principles to guide or inform the design development of product and services” (Sanders 2008: 14). This approach includes methods and techniques coming from behavioural, anthropological and social sciences, as well as from the engineering field (e.g. contextual inquiry, lead-user innovation, human factors and ergonomics).

Multiple and diverse activities have been carried out during the PhD work and it has been applied more than one design approach and different research methods that are included in more than one area of Sanders’ map. In order to better understand the PhD path, the map has been adopted as a reference framework which guided the classification (where possible) of the thesis activities on the *approach* and *mind-set* axes.

In the graph below, the PhD activities have been organised following Sanders' map.

Looking at the graph, it is evident that the activities are placed in the lower section of the map, namely the area included between Expert/Participatory mind-sets on the horizontal axe and Research-Led approach on the vertical axe, because the user has experienced different degrees of involvement during the PhD design process. In some cases s/he had an active role, while in others her/his participation was more passive; for example, with regard to the experimental exercise, the user was involved as subject of an experiment and s/he has a passive role consisting in the execution of ATM tasks and the compiling of questionnaires already defined and prepared by Human Factors and Neurophysiology experts (Expert mind-set). Also in regard to the Wizard of Oz activity, the user had a more passive role as s/he had just to test a Remote Tower CWP prototype previously arranged by HF experts, without a direct involvement of the user in the development of the above-mentioned prototype (Expert mind-set).

During the focus group, on the contrary, the user had an active participation in the definition of the scenarios as s/he brought her/his expert experience especially for the scenarios technical aspects, including the usage of the domain language and the procedures order of application (toward Participatory mind-set).

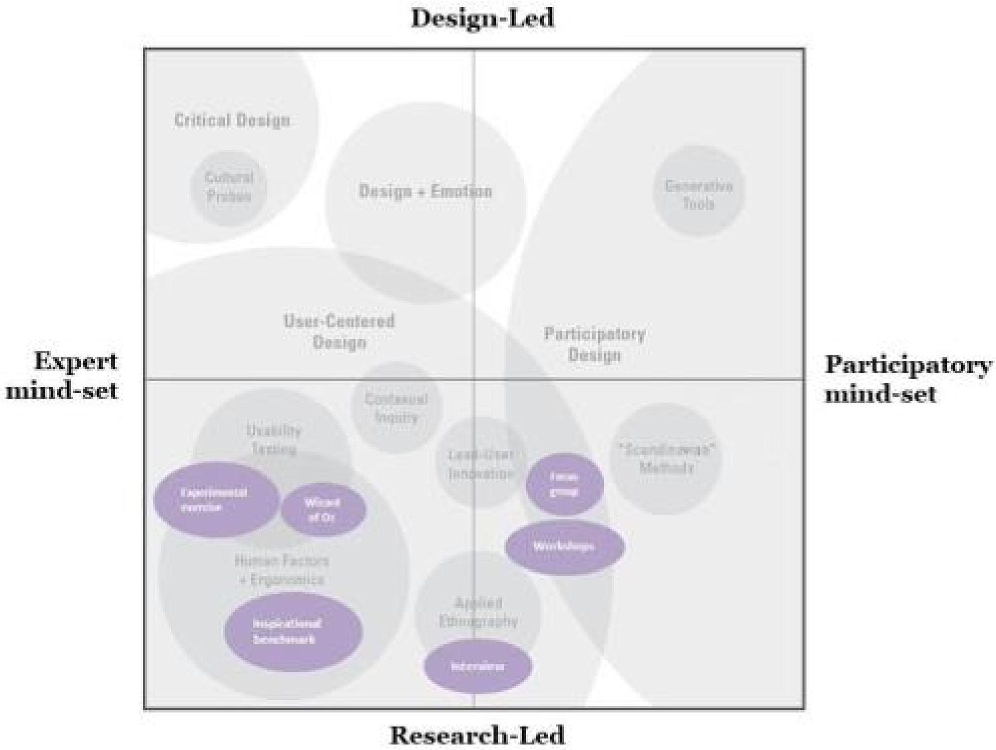

Figure 4 - PhD activities mapped on Sander's map

In addition to the above graph, the activities of the PhD have been organised in the Table 1, where each activity performed during have been associated to the results gained through the activity and it has been mapped with Sander's graph.

Table 2 - PhD activities and results mapping on Sander's design research map.

ACTIVITY	RESULT	MAPPING
• Interviews • Preliminary workshop	Scenarios	Applied ethnography
Experimental exercise	Trends on the impact of multimodal integration on Human Performance, Situational Awareness and Workload	Human Factors and Ergonomics
Inspirational benchmark	Set of existing multimodal technologies	
First workshop on the concepts	Preliminary ideas of multimodal interactions and tools (see table 10)	User-Centered and Participatory Design
Second workshop on the concepts	Detailed multimodal interactions ideas represented with graphic illustrations	
Wizard of Oz	Improved set of the first graphic illustrations version	Usability testing
Focus group with the end-user	• Micro-scenarios of the operational context • Graphic illustrations inserted in the micro-scenarios	• Participatory design • User-centred design

All the activities in Figure 4 constituted the framework of the co-evolutionary design approach that has been adopted for the design process described in this thesis. This approach can be placed between the User-Cantered Design area and the Participatory Design zone.

Starting from the embodied cognition and the multisensory integration, the co-evolutionary approach analyses how the development of multimodal solutions, able to support the Human Performance in the Remote Tower Operations, can lead to the elicitation of user's operational needs in a new operational context.

The co-evolutionary design methodology is structured in three main phases: problem setting, concept generation and concept development. According to this approach, the concepts generation, the user research and the technology selection should be carried out in parallel, so that each step of the process can provide inputs and enrich the others:

4. **Problem setting**: in this first step, inputs on technologies and/or evocative ideas on multisensory interactions and integration have been collected from multiple domains, enriched by the review of the ATM literature and the experimental exercise in order to identify the target users, their needs and some examples of future scenarios of RTOs. In particular, the following activities have been performed during this phase:

    - **Design questions and definitions:** to identify the target users, to model their activities, to identify the relevant scenarios and to define the design space.
    - **Experimental exercise** to gather trends on the impact of the multisensory integration on Tower Controllers' performance.
    - **Inspirational benchmark** to take inspiration from examples of innovative multimodal interactions in different fields of application.
    - **Preliminary multimodal interactions definition** to define a set of parameters to be used to collect information on multimodal interactions.

5. **Concept Generation**: during this phase, the first inputs on multimodal

interactions have been elaborated and inserted in the context of Remote Tower Operations, with more details on RTOs with respect to the problem setting. The results were a first set of graphic visualisations of the multisensory integrations that have been produced with the support of two illustration and graphic design experts; then a focus group with two Air Traffic Controllers has been organised, in order to assess the feasibility of the concept in the RTO scenarios.

6. **Concept Development**: in this phase the draft version of the multimodal technology concepts developed in the previous steps, have been finalised with the support of an Air Traffic Controllers, who gave their support in developing coherent Remote Tower scenarios where the suggested multimodal interactions could be explored and deepened with additional design research activities. The scenarios of RTOs and the concepts of interactions have been then integrated in the form of a storyboard describing the interactions in the context of use.

Chapter 2

The agent's body in a multisensory system

2.1 Embodied cognition

An increasing number of scientific studies exploring the approach of embodying cognition have highlighted the importance of exploring the perception that the human being has of her/his body and of its interaction with the environment s/he is immersed in. The aim of this theory is to discover and understand the full range of perceptual, cognitive, and motor capacities that we have as capacities that depend on the features of the physical body (Wilson, 2002, Borghi and Cimatti, 2010).

Embodied cognition is a theory derived from the studies of some philosophers, cognitivists and researchers of the field of artificial intelligence, according to which the human body and its physical and perceptual mechanisms have important influences on the nature of human mind.

Wilson et al. reported the following four examples of phenomena that inspired the science of embodied cognition:

1. *"We typically gesture when we speak to one another, and gesturing facilitates not just communication but language processing itself (McNeill 1992).*
2. *Vision is often action-guiding, and bodily movement and the feedback it generates are more tightly integrated into at least some visual processing than has been anticipated by traditional models of vision (O'Regan and Noë 2001).*
3. *There are neurons, mirror neurons, that fire not only when we undertake an action, but do so when we observe others undertaking the same actions (Rizzolatti and Craighero 2004).*
4. *We are often able to perform cognitive tasks, such as remembering, more effectively by using our bodies and even parts of our surrounding environments to off-load storage and simplify the nature of the cognitive processing (Donald 1991)."* (Wilson, Robert and Foglia 2017: 2)

From a philosophical point of view the embodied cognition argues that a person's cognitive processes are strongly influenced and moulded by the body. According to

Varela et al. the definition of the embodied cognition is therefore:

> *"By using the term embodied we mean to highlight two points: first that cognition depends upon the kinds of experience that come from having a body with various sensorimotor capacities, and second, that these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological and cultural context"* (Eleanor Rosch, Evan Thompson, Francisco J. Varela 1993: 172-173).

Another researcher that according to the opinion of some scholars, this definition is quite broad enough to fall within the concepts of extended cognition and situated cognition, and this implies that such theories are not sufficiently defined and carefully separated. In this regard Michael Dawson affirms that:

> "*In viewing cognition as embedded or situated, embodied cognitive science emphasizes feedback between an agent and the world. We have seen that this feedback is structured by the nature of an agent's body.*" (Michael Dawson 2014: 62)

With regard to the agent's body, Dawson's statements suggest that the degree of embodiment experienced by agents can be different, depending on the distinct kinds of bodies they own. Considering that, his idea is that "*Embodiment can be defined as the extent to which an agent can alter its environment*." (Michael Dawson 2014: 62)

It can be argued that cognition is embedded when features of the agent's body have a fundamental causal or physically constitutive part in the formation of cognitive processes. The majority of the researchers in philosophy on mind and cognitive science did not consider the body as a central element in the understanding of the nature of mind and cognition. In embodied cognition proponents' view, this idea of the body as peripheral actor was judged a serious mistake, as the nature of the dependence between body and cognition can be unexpected and it can offer new paradigms of conceptualising and studying the mechanism and the dynamics of the cognitive processes. One big challenge for cognitive psychology and neuroscience is to understand how perception, cognition and self-consciousness arise during natural interaction with the environment.

Traditional approaches to cognitive science look at the mind as a cluster of abstract mechanisms which are independent from the human senses and the sensorimotor human capabilities. Despite the acquired knowledge of the functioning of cognitive systems, this type of approach still attaches less importance to the physical and sensory experience that human beings continually and naturally experience in the surrounding environment (Wilson, Robert and Foglia 2017).

One of the first works done to give a new direction to the cognitive sciences with a more specific focus on the phenomenological perspective has been the book *The Embodied Mind* by Varela, Thompson and Rosch 1991, which states that the dichotomy between the internal symbolic representation and the pre-given element of the external world should be overcome, "*as it is unable to accommodate the feedback from embodied actions to cognition via the actions of a situated cognitive agent*" (Wilson, Robert and Foglia 2017: 4).

Varela, Thompson and Rosch (1991) put emphasis on the experience human beings have of the world, which is influenced and defined by the interactions between the organism physiology, its sensorimotor mechanisms and the environment. The concept of the interconnection between body, brain and world is the centre of their theories on embodied cognition, which the researchers built "*on the classical phenomenological idea that cognitive agents bring forth a world by means of the activity of their situated living bodies*" (Wilson, Robert and Foglia 2017: 4). From this perspective, one's knowledge is the product of the engagement of the agent body with the surrounding world, instead of being only a passive actor, who is prisoned in pre-existent situations or determined only by personal construals. In this regard, according to the embodied cognition theories, cognitive processes such as the formulation of thoughts, concepts, categories and the elaboration of reflections, judgments and decision-making processes are strongly shaped by body-related factors such as the sensory system, the ability to move, to interact with the environment, as well as ontological concepts about the reality that surrounds us, which are acquired and assimilated by our brain and, at the same time, by our body. According to scholars who are involved in embodied cognition, each of these factors is affected also by the body.

In the Neuroscience domains the concept of embodiment cognition has been described as the product of brain processes of i) multisensory integration of stimuli coming from the body (i.e. sensorimotor, proprioceptive, vestibular, kinaesthetic) and the external environment (i.e. visual, audio, tactile, vibration) and ii) their combination with motor actions elicited to interact with the world.

The biggest differences between the traditional cognitive sciences and the new theory refer to the different ideas of what cognition is, how it functions, and when a system works properly. The embodied cognition refuses the classical dualism mind-world and it highlights the importance of analysing the cognitive processes taking into account the environment in which they take place: the environment can be social, natural and cultural. It also refuses the dualism perception-action, reason-emotion and obviously the mind-body opposition, which is clearly expressed with the term "embodied cognition". In this theoretical framework, the human being is not a mere observer of the world but an active agent and, thus, the human cognitive processes can be linked to the human capability to interact with the environment.

This thesis has philosophical roots in the theories of Kant Husserl and Merleau-Ponty with the work of *The phenomenology of the perception* (1945), from which contemporary currents have been influenced, along with recent research work in the field of linguistics, artificial intelligence, robotics, neuroscience and cognitive sciences. According to Wilson et al.:

> *"Embodied cognitive science pushes phenomenological accounts in new directions. It seeks not so much to understand how physicality opens up the experience of the self, the world and the others, but rather aims to specify the mechanisms that explain just how cognition is grounded in, and deeply constrained by, the bodily nature of cognitive agency"* (Wilson, Robert and Foglia 2017: 6).

The embodied cognition has been influenced also by the phenomenology and the ecological psychology of James Gibson who transmitted the refusal for the body-mind dualism, together with the idea of the centrality of the body experience and perception in the empirical research. One example that can help to understand Gibson's theory refers to how the process of vision works. He started from analysing the mechanism involved when the visual system has to reproduce the three-dimensional surrounding world, using the information provided on the 2D images on the retina, and then he concluded that the 2D information does not represent a problem for the visual system, as it is composed of an active organism which is immersed and which interacts in a reach visual environment, thus being able to elaborate a realistic representation of the elements in the field of view. This approach to the visual system was used by Gibson

> *"to attempt to specify this richness, the information in what he called the ambient optic array, especially invariants in that array, which can be used to distinguish agent-dependent and objective features of one's environment."* (Wilson, Robert and Foglia 2017: 7).

In addition, Gibson's emphasis on the importance of the body perception in the world and its interaction with a visually reach environment has been considered one of the first contribution to the embodied vision and its theory about the vision has been adopted also in the research of information processing of views, as in the case of the work by Rock (1983, 1997) and Marr (1982).

Other researchers in the field of robotics, including names such as Rodney Brooks, Hans Moravec and Rolf Pfeifer, say that machines equipped with a real body that can experience the surrounding world are able to reach or approaching true artificial intelligence. Some neurobiologists such as Damasio and Edelman have explored the relationship between brain structures, body and mind-related aspects such as will, emotion, self-consciousness, and consciousness.

Compared to the classic approach, embodied cognition argues that without the involvement of the body, both when we perceive the stimuli of the outside world through the senses and when we act in and on the world, thoughts would not have the same expressive force and would not be complete. This approach offers the advantage of investigating and deepening the behavioral processes of human beings during interaction with the environment; and through this interaction, it tries to understand the role that the human body plays in cognitive processes, illustrating how it is capable of influencing the activities of the mind.

Physical features represent both a limit that separates the self from the other, and the vehicle through which human beings can intervene on the shape and contents of the interaction, also playing an active role on the world around. The body, in conjunction with mind processes, prepares and governs the transition from intent to action; it is the instrument through which this can happen and with which to produce effects on the world and to attribute meaning to it.

As the central idea behind the embodied cognition is that the cognitive processes are shaped by the body perception and its interaction in the world, it is useful to analyse the nature of dependence of cognition and body considering which role the latter plays in the former. Wilson et al. describes three roles of the body, together with the implications of each category on the embodied cognition theories. According to this classification, the body can represent a constraint on cognition, a distributor with regard to the cognitive activity and/or a regulator of the cognitive processing. Here below the three categories are summarised:

Body as Constraint: the body represents a constraint for the mental representations elaborated by the cognitive processes, both in regard to their nature and to their content. This idea of the body entails that the body characteristics can enable the formation of specific cognitive mechanisms and at the same time they can make difficult or impossible the formation of some forms of cognition; and also that changes in the body can produce changes in the cognitive processes.

In this first category fall the research studies of Lakoff and Johnson on the concept of metaphor and its influence on the cognition and the work of Varela, Thompson, and Rosch on Enactivism, in particular with regard to the domain of the perception and categorization of the colour.

Body as Distributor: the body in this case is considered as a mean to share cognitive tasks between the brain and the body. The implications of this idea of the body are that its structures and elements are part of a physical system that can be an enabler of cognitive processes; and moreover, cognitive systems are composed also of non-neural elements of the body end of inputs coming from the environment outside the body boundaries.

The idea of the involvement of non-neural structures and the environment in the concept of the body as a distributor creates a relation between the theory of embodied cognition and those on the extended mind, which deal with the concepts of realization and scaffolding that have been studied by some researchers by Wilson and Clark between2003 and 2009.

Body as Regulator: in this case the body is considered as able to regulate the cognitive processes over time and space, ensuring that cognition and action are tightly coordinated (Wilson, Robert and Foglia 2017). One implication of this categorization of the body is that physical mechanisms (e.g. the sensorimotor system and the proprioception) allow the body to response and adapt to a changing environment, through the performance of complex behaviors.

Additionally, physical states affect the thought and perception that is inherent in the time and space in which it is present, as in situations where the memory is affected by the effects of the postures that the body takes or in the way human beings approach and deal with a situation. Via the body, the external environment is able to affects task performance, decision making and natural activation of attentional system (Goldman & de Vignemont, 2009).

In the last decades the studies on the embodied cognition gave raise to several versions and interpretations of the theory, however there are some common assumptions as the overcoming and, in some cases, the review of two metaphors used to describe the cognitive processes: the “sandwich” model of cognition and the “computer” metaphor.

The first metaphor has been used by Susan Hurley in her book *Consciousness in Action* (1998), in which she explains that the two slices of the bread correspond, respectively, to the perceptual input and to the behavioural output, while the meat inside are the cognitive processes. This idea affirms a neat difference between perception and action from one side, and cognitive processes from the other side; it also gives for guarantee that the sensory system and the motor domain are at the opposite, without taking into consideration their integration and communication. In addition, it does not consider that the human thinking and the decision processes are influenced by the interaction with (and the perception of) the world around us.

The cognitive scientists who adopted this metaphor focused their attention on the cognitive processes, without considering the implications of the body in the above-mentioned processes. According to Caruana and Borghi, perception is an explorative activity and it is facilitated by sensorimotor contingency, by the know-how and by specific abilities that humans acquired with the experience (2016).

The second metaphor is at the basis of the so-called representational and computational theory of the brain.

According to this theory, the human cognitive performance is explained as the result of algorithms in the brain, similar to the language of a machine and based on symbolic structures. The cognitive processes are, thus, computational procedures that elaborate mental representations of the world. These mental representations are necessary for the perception of the outside world, because they are the inputs used by the brain to activate mental processes as for example, the decision-making activity, the information acquisition, the information collection in the memory and the deductive thinking. The majority of the classical cognitive scientists define the mental representations as scientific entities that have neuronal configurations in the nervous system or entities which constitute the ontological knowledge of a mind (Caruana e Borghi 2016).

The representations are characterised by content and a format/shape; the format has been compared to the symbolic structures of a digital computer and they are not related to the sensory modalities used to perceive the environment, or better say, they are related to the world only in a first step of the interaction. The human senses, in fact, collect inputs that are translated in an independent language used by the brain to process the information and, for this reason the format of the mental representation is considered a-modal.

Another researcher that deals with the concept of mental representations is Lawrence Barsalou, who analysed the perceptual symbols theory in his studies from the 1999 to 2009. According to his theory of mental representations, cognition does not consist of a-modal representations that establish links to their referents in the environment, but these representations are strictly related to the information coming from different sensory modalities. In this regard, the symbolic structure representing the shape of an object (e.g. a ball) when it is not present in the field of view, depends on the same neural cells that are involved when that shape is perceived. This statement suggests that the cognitive system and the perceptual mechanism share mental representations and that the former re-activates the latter also to simulate situation when there is not the actual perception of an object.

With the embodied cognition approach, the classic concept of mental representations has been substituted by the bodily-format representation, based on the idea that many cognitive processes are executed also through the information coming from the sensory and motor systems. The embodied cognition approach does not foreseen a hierarchical relation between the perception, the cognitive and the motor processes, but there is a circularity between when the human being perceives a situation, when s/he decides to act and when s/he acts in the world: the action influence both the perception and the action (Caruana and Borghi 2016).

One of the merits provided by the embodied cognition theory is the idea that the visual experience is a result of the dynamic interconnection with the environment, as well as a bigger awareness on the contribution of the sensorimotor system in "*providing the organism with the proprioceptive/kinesthetic feedback necessary for the sense of ownership of movement*" (Wilson, Robert and Foglia 2017: 16). In this regard an example is the situation in which we touch an object; in that case we have both an experience of the object and of the movement of the body and of the control of the body during the execution of the action.

The idea that the sense of controlling the body is the result of interactive processes with the environment (e.g. sensorimotor mechanisms) suggests that the self-awareness is influenced by the embodied experience. In support of the relation between consciousness and action, studies on brain imaging have demonstrated that the illusion of control in schizophrenic patients is combined to the failure of the mechanism that correlates the intended motor commands to the expected consequences of an action (Frith at al. 2000). This study suggested that the capability to handle conscious thoughts might involve the same processes that are commonly used during the interaction with the environment.

This chapter provided an introduction to the embodied cognition without the pretension of being exhaustive and to illustrate all the currents and implications related to it. This theory has been analysed taking into consideration the scope of the PhD work, thus focusing mainly on the concept of agent's body and of its characteristics, interaction with the environment and the implications on the cognitive processes. The modalities of the body interaction with the world, in particular of the role of the different sensory channels on the construction and execution of actions in the environment are explored in the next chapters.

2.2 Multisensory perception

Reclaiming the embodied cognition theory and, thus, the crucial role of the body in the cognitive processes, a strictly related concept to the embodied cognition is the multisensory integration, which foresees the involvement of the human physical perception while acting in the world, and the influence of cognitive and body perception when collecting information and taking decision on the world around us. It studies also how the nervous system integrates the information from different sensory modalities (e.g. sight, touch, sound, taste and smell) and how these stimuli interact between each other. The advantages of combining multiple sensory modalities could result in a coherent representation of objects and in meaningful perceptual experiences of the environment humans are usually immersed in.

In everyday life humans interact with the external world through their body and they are always aware that the body belongs to them and that they are physically present in the world, even in situations where they might not be conscious of the full spectrum of perceptions. The surrounding environment is full of perceptive elements that arrive to the human sensory channels when doing day to day actions, as for instance while cooking a dish of pasta with a friend. During this common action (mainly for Italian people), the subject is supported by the information coming from different sensory modalities to conclude her/his actions. Through the visual information and the proprioception (the position of the body in the space) s/he is able to move in the space, while the auditory information and the lips movements allow understanding the friend’s speech, and the tactile stimuli support the action of gasping the package of pasta. In addition the sense of taste and the visual channel finally help to understand the pasta is added to the dish.

This example let us think about the idea of sensory modality and how they are usually described and commonly considered. Actually the senses are widely known as five and, analysing this idea from different perspectives, it can be concluded that the number of human senses is not necessarily five. For example, from a physiological point of view a sensory channel is based on the concept of receptor, a nervous cell that is responsible for the transformation of a stimulus in a signal in the brain. There is a variety of receptors on the human body, as those distributed on the skin, where there are some receptors that allow us to perceive the different temperature levels (e.g. warm and cold), together with some nerves endings on the body, which are sensitive to the skin pain perception. The same happens with the tongue that is characterised by multiple receptors, as those reacting to sweetness, sour and savoury.

The stimuli that arrive to the receptors are, on the other side, categorised in three types: electromagnetic energy, chemical and mechanic stimulations. The receptors have the task of collecting those kinds of stimulations and, thus, taking into consideration the physiological perspective, it can be argued that the senses can be considered as three (Bruno, Pavani and Zampini 2010).

According to the human sensory system definition on Wikipedia, the human senses are six, where the sense of touch is included in the somatosensory system together with the sensations of the "*pressure, temperature (warm or cold), pain (including itch and tickle), and [those] of muscle movement and joint position including posture, movement, and facial expression (collectively also called proprioception)*" (Wikipedia 2017).

If we analyse the phenomenon from the classic philosophical perspective, before the modern science there were already theories on the multisensory perception; in fact for example in the Aristotelian philosophy the senses are considered six, because besides the philosopher speaks also of the "common sense". Aristotle stated that the common sense had two functions; from one side it was responsible for the human consciousness of being able to perceive the world through the senses, and on the other side the sixth sense allow us to perceive the objects characteristics as the size, the extension, the shape and the movement.

The human senses are generally studied as separated input systems for at least two reasons. The first one is that the receptors, which receive inputs from the surrounding environment, are situated on different parts of the human body, according to their different functions; the second reason is that so far it has been considered that there are specialised areas in the brain for any kind of sensory modalities and that these primary sensory areas have a specific and different architecture for each modality (Bruno, Pavani and Zampini 2010).

In recent years the idea that in the brain different areas correspond to different sensory modalities has been called into question by neuroanatomy and neuro-physiology studies on Primates and by neuroimaging studies on humans. These studies have demonstrated that the first signals of a multisensory integration takes place in an area that was previously considered specifically-made for one sensory modality.

The modern science has given empirical data to the theories of multisensory perception that, as said, already emerges thousands of years ago with the philosophy.

Among the examples of the multisensory perception and integration there are several examples of illusions or effects that suggest a deeper analysis of how the information of multiple sensory modalities influences human perception. Two well-known tests on this issue are reported below, namely the McGurk effect and the experiment of Jousmaki and Hari carried out in 1998.

The McGurk effect studied by Harry McGurk and John McDonald in 1976 describes an acoustic vision illusion dealing with the integration of lips movements with a spoken message. The subjects involved in the experiment looked at a video of a person pronouncing only the phoneme /ga/ and it was asked to the participants to report which phoneme they were listening to. They argued that they perceived the phoneme /ba/ but they also reported to listen to the phoneme /da/, which was never pronounced in the video. If the subjects closed the eyes, the sound perceived was the one effectively pronounced, thus /ga/ and not /da/. When experiencing this illusion, the lips movements overcome the auditory input, influencing what the subjects believed they were hearing. The brain is often unaware of the differentiation between information coming from separate sensory modalities and when the brain tries to give a sense to the conflict between two inputs coming from different sensory channels, one of the two can change the real stimuli providing a different perception of them.

The importance of multisensory integration of both visual and sound stimuli is often underestimated, which implies impossibility to fully appreciate and perceive not only the richness of the body and the physicality, but also the richness and complexity of the world surrounding us.

An example of multimodal integration of sound and touch inputs comes from the test performed by Jousmaki and Hari in the 1998. The experimenters asked to the subjects to rub their hands and to report if the hands were smooth or rough. During the test, a microphone recorded the sound of the rubbing that was provided to the subject through the headphones. In some cases the sound reproduced was the real one; in other cases its frequencies were manipulated. The results demonstrated that when the high frequencies were amplified, the subjects reported that the hands were smooth; while when the sound was diminished, the hands were perceived as rough. In this case, as for the acoustic visual illusion, the sound perception distorts the information coming from another sensory modality, namely the touch.

In some cases the multisensory collaboration allows to perceive more robust and more reliable data regarding objects or events of the environment, as demonstrated also by Ernst and Bulthoff (2004). Sometimes the information from different senses compensates each other, as for example when touching an object the tactile perception gives the possibility to "view" with the hand the back part of the object, out of a person's view (Newell et al. 2001).

As for the embodied cognition theory, one of the pioneer of the new concept of human senses as perceptual system is James J. Gibson, who introduced the idea that the sensory channels are elements of a multisensory system, which allows the human being to perceive the world and to interact with it.

Generally speaking, a system can be defined as a cluster of elements that are interconnected, interdependent and that constitute a unified whole. A system has a structure characterised by a set of functions which concur to the achievement of purposes. Moreover, it is usually immersed and influenced by its environment and at the same time it is defined by temporal and spatial boundaries.

Gibson, through his theories, emphasises the ability of the perceptual systems to cooperate when collecting information from the world. The new concept of “perception” introduced by Gibson was in conflict with the previous theories which had their roots in Fechner psychophysics. According to these theories the perceptive process was unidirectional, that means that the information comes from the world to the brain and ends with a process of consciousness, without any consequential activity from the human being on the world. With Gibson the human being is considered more as an active agent and the perception as an active multisensory system. This concept takes into consideration the involvement of motor processes, the perceptual systems and the cognitive processes, which are the basis also of the idea of the self-perception and it is fundamental also to understand the cognitive processes in a multisensory environment. The perception in this new conceptual framework is a sort of explorative activity in the world.

The perception in Gibson theory has three characteristics:

1. It is direct: this means that it is not the result of an inferential process applied to sensory representations;
2. Perception is action, in fact when the human eye sees something, it is not merely recording information, but it is actively manipulating the external inputs through its organic and mechanical structures and also through the head and other body movements;
3. Perception is what the objects and, generally, the outside world invites us to do in the environment, for this reason Gibson’s idea of perception is also the perception of affordance (Caruana and Borghi 2016).

These ideas opened the discussion also to the differences between a semantic knowledge of the reality and a practical one, more related to the concept of the affordance. The two kinds of knowledge have been studied by physiologists, as Mishkin and Ungerleider, and by neuropsychologists, as Milner and Goodale, between the 80’s and the 90’s through the analysis of the consequences that traumas in the parietal lobo and the temporal lobo provoked to their patients in the perception of and the action on objects. In this study we will not enter in the merit of these ideas, but it is important for understanding the relation between the body, the objects and the environment to consider Gibson's theory of perception of the results of the objects' invitation to do an action on them and in the world.

2.3 The multimodal experience of the body in the space

As stated in the previous chapters, one of the way that the human being uses to know his/her body is through the senses, that means through the tactile sensations, the perception of the temperature, the feeling of hurt and also through the position of the body in the space. The last one is a sense called proprioception, based on the information coming from the muscles, the tendons and the articulation that we put in place in order to modulate the body position and movement in the world. The proprioception is fundamental for the feeling of "ownership", the idea that the body belongs to us. The knowledge of the body cannot be based only on the sensory perception, but it is one of the modality involved in the sense of ownership. The physical perceptions are initially interpreted according to a map located in a specific area of the brain, the primary somatosensory cortex. As the human receptors for each sense are in different number and density on the body for the different sensory modalities, the area in the brain dedicated to one sensory modality can be bigger based on the number and density of the receptors of that modality. For example, on the lips there is a higher quantity of receptors that on the legs, thus in the brain the area dedicated to the representation of the libs is more extended than that of the legs representation. If the human mind should represent the body according to the map of the primary somatosensory cortex, it would have a distort image of the human body, that is well-known as somatosensory homunculus.

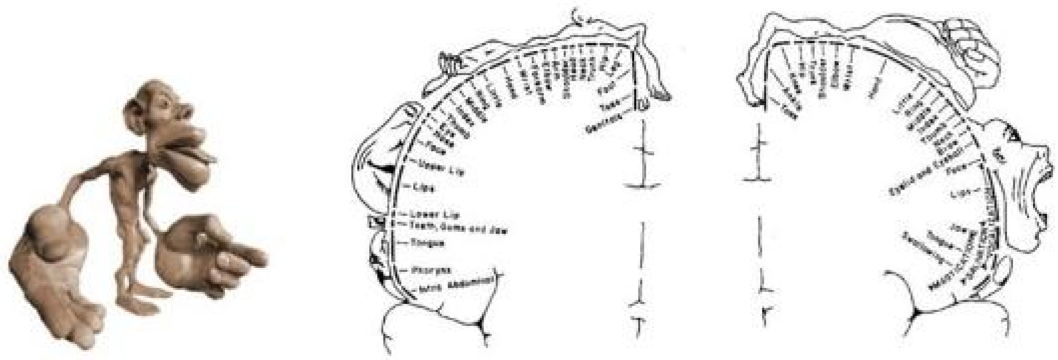

Figure 5 - On the left side the somatosensory homunculus; on the right side the Penfield's map of the body.

The existence of these distortions in the brain has been demonstrated through the famous illusion of Weber. It involves the tactile stimuli provided to two different areas of the body. When they were given to an area with more receptors and to a region with less receptor, even if maintaining the same distance between the two points, the perception was that this distance improves on the part of the body with a lower number of receptors. This evidence suggests that some physical perceptions could be influenced by the distort representation of the body in the brain.

It is clear that the perception of our body is not limited to the information received from the senses and from the dimensions of the dedicated area in the brain. Even if it is possible to fall into the illusion, in everyday life humans are aware of the real dimensions of the body, that means knowing that hands are no longer than arms and they don’t usually confuse stimulation on the left finger, if in reality it is on the right one. This depends on the fact that the brain is able to elaborate a representation of the body which is more similar to the real one. For this reason, the most widespread idea is that the following three properties of the body, the geometry of the body, the mereology of the body and the topology of the body are the results of an integration of motor and multisensory information and not only the product of information from the single senses. The geometry of the body refers to the identification of the extension and the length of the different parts; with the mereology of the body is defined the

categorization of the different parts of the body; while the topology of the body is described as the spatial relations between the body parts.
Moreover, in order to understand the above-mentioned representation of the body, thanks to the study of two neurologists, Head and Holmes, it has been highlighted that the human mind has two different representations of the body. The first one is called body schema and it is unconscious and based on sensorimotor and proprioceptive stimuli; the second one, the body image, is especially based on the visual inputs of the body and it is a conscious perception.
This theory has been elaborated from experimental observations of the behaviours of patients with two kinds of traumas, one on the body schema and the other on the body image. The first case was studied by Paillard in 1999, and it involved a patient who was able to tell which part of the body was stimulated with a tactile input and she was also able to indicate the stimulated area on a general picture of the body; meanwhile she could not manually point at her body part interested by the stimulus. In the second case, in an experiment by Paillard, Michel and Stelmach of 1983, the patient was perfectly able to manually indicate the exact point of the stimulus, but she did not perceive any tactile input on her body. (Bruno, Pavani and Zampini, 2010)
This categorization between the body schema and the body image is used in numerous studies and theories, even if it is still subjected to criticism; for the purpose of this study this theory is adopted to say that the body representation should be integrated with other information, in order to have a more realistic idea of the body.
All the above-mentioned descriptions of the body representations try to explain the feeling of body ownership that nowadays is still not completely clear and shared. In their word Jeannerod and Martin hypothesized that this feeling is the result of our capability to associate the human physical perceptions in a specific space (2007; 1995). According to this idea, the space is represented by the body schema which is integrated by the multisensory information that is available to the human being while interacting with the world.
In addition to the multiple body representations, another issue analysed to better

understand the importance of the body perceptions is the interaction of the body with the space it is surrounding by. The multisensory space of the perception influences the human capability to orient the attention on a relevant area inside the environment and to select the necessary information among the multiple stimuli in a specific moment. It is widely recognised that the position of the information in the space has an impact on the process of selection, as for example when listening to someone speaking in a crowd room. In this case, the visual information of the lips movements, associated with the sound of the person's speech help to identify the boundaries of the space of attention.
Several studies have explored the effects of the combination of visual and auditory stimuli, as well as of visual and tactile perception. In the following paragraphs, some examples on this topic are reported.
The neurophysiologists Hyvarinen and Poranen in 1974 carried out an experiment with a macaque during which it was observed that when stimulating a part of the skin some cells in the brain reacted and among them, there was a little group of cells that activate when a visual stimulus was presented in the area of the skin able to reproduce the same reaction in the brain. This phenomenon appeared only when the area of the skin stimulated was visible to the macaque; while on the contrary, when it could not see it or when the visual input was on the opposite side of the body, there wasn't the activation of the above-mentioned cells.
The results of the test suggested that in the brain bimodal responses could occur and that the region of the brain interested by this phenomenon is sensitive both to auditory and tactile stimulations. The area of the brain interested by the neuronal responses studied by Hyvarinen and Poranen is the posterior parietal cortex, responsible for sensorimotor stimulation involved when interacting with the surrounding world. Studies carried out by Rizzolatti (1985) suggested that also in the premotor cortex there are bimodal neurons; this area of the brain is also involved in the planning and in the spatial guidance of movement, as well as in the sensory guidance of movement and in the control of the trunk muscles of the body. These brain areas are all related to the planning and the control of the actions and this corroborates the idea of a strictly

correlation between the perception of the sensory stimuli and the actions and interactions performed in the environment.

A similar study has been done with humans by Spence, Pavani and Driver (2004) where the participants received a tactile stimulation on the thumb or on the index finger and they had to answer, as fast as possible, to which of the fingers the stimulation was provided. At the same time, a visual input was provided or from the same side of the sound or from another position. Even if the participants were required not to consider the visual information, it was noted that when the visual and tactile stimuli came from the same direction, the performance was better than when the sensory stimuli were incongruent. This effect has been recalled the *cross modal congruency* effect as it is related to the relation between cross modal stimuli.

To these studies, additional tests demonstrated the integration between different sensory modalities. In this regard, Spence and Driver explored the implications produced by a visual stimulus on the execution of an acoustic task, when the former was provided from the same or a different position of the latter. During the test, the subjects listened to two acoustic messages provided one from the right and the other from the left side; at the same time two videos located on the same positions of the acoustic inputs were showed to the subjects. In some cases the person in the video repeated one of the two acoustic messages or s/he just moved her/his lips without speaking. The task of the subjects was to repeat one of the acoustic messages and also to look at one of the videos.

The results demonstrated that the subjects' performance was higher when the acoustic message corresponded to the visual one, as the lips movement supported the recognition of the message. Moreover, when the two inputs came from the same area of the space, the performance improved compared to those cases when the two messages were located in opposite sides, one on the right and the other on the left of the participants. This second evidence suggested that when the attention was focused on the same portion of the environment, there could be an advantage in the elaboration of the information.

The same researchers did another similar experiment during which the subjects had to indicate the position where an auditory input (73% of the total time) or a visual stimulus (the remaining 17% of time) appeared. The stimuli could appear at the bottom right/left or at the top right/left of a screen, while the subjects had to look at the central point of the space. Before the provision of the acoustic stimulus an arrow appeared suggesting the most probable location where the sound would have come from. This suggestion guided the attention of the subjects, who had a more accurate performance when the sound effectively appeared from the side previously pointed out by the arrow. The results showed also that the subjects had a propensity for focusing on the same side of the acoustic input also when a visual one was provided.

Studies on this topic have been done also for driving tasks, in particular on the analysis of the driver distribution of the attention when using the mobile phone while driving a car. Spence and Read (2003) carried out a test where the participants had to drive a car in a simulator, reproducing the images of city traffic, and they had also to repeat an acoustic message that in some cases was provided in the front of the participants, in other cases from their left side. Meanwhile additional irrelevant acoustic information came from another source located in the car. It was noted that the execution of the task had higher values when the message to be repeated was provided from the frontal position, the area where the subjects were already focusing their attention during the driving task.

The example of focusing the attention on an element of the space in a crowd room (voluntary action) and the studies of Spence and Driver (involuntary movement of the attention) highlighted that it is more natural to focus the attention on two stimuli in the same portion of the environment, while it is more demanding to concentrate on sensory information coming from different directions.

The above-mentioned studies on the multisensory integration could have a crucial role in the design of multimodal interfaces and, thus, it is worth considering it when designing multimodal interactions and interfaces, in order to better catch the attention of a user on a specific element, improving his/her performance in the execution of a task. It is also true that the way in which the attention is oriented during the interaction with these systems is not the only factor to influence the design. In fact, the level of complexity of the multimodal interfaces can depend also on the amount and variety of the information provided and on the modalities of interaction with the system. However, the results described should be considered in the development of concept of multimodal interactions, as there could be positive impacts on the performance of tasks, in terms of accuracy and reliability of the answers provided by the users of a system. The potential benefits of the multisensory integration have been explored with the experimental exercise described in this study in Chapter 4 and in Chapter 5.

2.4 Multimodality in Air Traffic Management domain

As regards the issue of immersion and the use of multimodal technologies to support the work of the controller, many researches and prototypes have been carried out in recent years, both in relation to the interaction of the single operator with the tools and to the collaboration between operators, passing through the systems used. Here below are reported the most interesting examples for the topic of this thesis, as they deal with the physical interaction of the ATCO with working tools (e.g. through touch and arm gesture) and with the development of an innovative Flight Paper Strips design.

In a 2016 project, Cordeil and Dwyer studied the development of immersive technologies that can help the controller in managing traffic, both in real time and off-line. The two researchers designed two immersive solutions for real-time control scenarios and a prototype for off-line aircraft trajectory management contexts. In the first case, they took into consideration the thermal/infrared technology able to allow the controller to manage the movements of the vehicles in the area of their responsibility even in situations of poor visibility. In this way, the controller cannot only better locate the vehicles but also increase the speed of traffic management and avoid the accumulation of movements delays, which would lead to a reduction in airport capacity and the potential holding of other aircraft.

A second solution for managing traffic in real time is the use of the Head Mounted Display that allows the controller to move within the (virtual) space of his responsibility by receiving detailed information on the vehicles. Moreover, this immersive technology allows the controller to manipulate the environment in which it is immersed to obtain useful information for traffic management, for example by zooming in on vehicles or by indicating the vehicles on which it wishes to obtain more information or by moving the type of display from the usual one infrared/thermal, through a vertical movement of the arm. The different types of interaction would allow the controller to manage the space in which s/he works in an immersive way, limiting the possibility of feeling out of the loop in a remote location and, thus, the risk of a negative effect on her/his task performance.

With regard to the off-line management, the researchers focused on the creation of a prototype able to support controllers and experts on the management of aircraft trajectories. The situation analysed by the researchers is that of a traffic peak that in some cases forces the ATCO to put multiple planes on hold, with the (possible) consequent diversion of some flights to different airports from their actual destination.

The prototype helps experts located in distant places to communicate and collaborate on the analysis of the aircraft trajectories that were involved (and in some cases changed) during the traffic peak, as well as on the identification of the reasons behind the peak. The benefits of such a system lie in the ability to manage the trajectories collaboratively also and especially from different locations, following by a potential reduction of the users' cognitive load and an improvement in the whole workflow.

As the two scholars argue, the aforementioned technologies are a first step towards the development of immersive systems able to help the operator in the safe and effective air traffic management, both in real time and off-line; in order to do this, further phases of evaluation and finalization of the above-mentioned technologies design are necessary, together with the indispensable contribution of the expert users during the development of the prototype.

Among the most studied tools by researchers and developers in ATC to improve the ATCOs' performance, there are the Flight Paper Strips (FPS). In the history of air traffic control, this tool has always played an undeniable role, as it provides information related to an aircraft (e.g. the type and its speed) and it is also used by the controller to annotate additional data related, for example, to a change in the vehicle altitude. In addition, the FPS are shared between the controllers to allow everyone to have a complete picture of the aircraft and vehicles operating at a specific time. The controllers often move the FPS in certain positions on their desk, as a way to remember an event in progress: this is the case of inspections on the runway, during which the FPS are placed in a different position (e.g. diagonal on the other strips), in order to keep a high level of attention on the event in question. The event, in fact, requires the controller to know that if an aircraft asks the clearance to land when the runway is not free, s/he should not give the permission to land but to perform a go-around up to the liberation of the runway. As Mackay argues “Strips form part of a controller's mental representation of the traffic and Strips also provide a focal point for updating mental images of the traffic and allow controllers to instantly communicate the current state of the traffic to each other” (Mackay et al. 1998: 5).

The physical interaction of the controllers with the FPS has been the subject of many researches that led to the development of the Electronic Flight Paper Strips (EFPS), which are an electronic version of the tool with the totally digitization of the physical component (i.e. the paper element). The benefit of this version is that it allows the controllers to have the aircraft information and related updates not only on the strips but also on other systems; the connection between the strip boars and the other electronic tools cannot be obtained with the traditional FPS. In addition, the EFPS have been adopted in some airports but not in all, since the physical manipulation is often preferred over the digital one.

Some of the systems developed to improve the FPS and the interaction between the controllers and this tool are, for examples, Digistrips and ASTER that show a virtual stripboard with electronic strips to the ATCOs thanks to the implementation of an LCD touch screen; while Camaleon and Strip’TIC are systems using the augmented reality potentialities to produce augmented paper strips, and which attempt to maintain the possibility to physically manipulate the strips in a similar way as the ATCOs do with the traditional FPS. Other examples that allow the information exchange and updating between the analogic (i.e. paper) and the digital tools are PADD and MouseLight, which add traffic content to the paper support using a mobile projector. When dealing with FPS, the most explored interaction modalities with this system (both electronic and augmented) consists of the digital pen adoption or the finger touch mode. With regard to the first case, Anoto is an example of how to directly manipulate data with a digital pen on an interactive interface; this technology have been implemented in relation to the Strip’TIC advanced prototype that is explained in the following paragraph.

Starting from the observation of FPS and EFPS uses, prototypes have been created that integrate the paper component with augmented reality instruments. This combination starts from the assumption that the physical interaction of the controllers with this instrument has a primary role in the management of the information in the space, as they can facilitate the transfer of a data to be memorized on the instrument, in order to lighten the cognitive weight when the air traffic control requires a greater level of attention. In this regard, Mackay states that "Controllers often take strips in their hands as a reminder to do something. They slide them left or right to highlight different conditions, such as two planes in conflict. Even the act of writing is important: controllers find it easier to remember something they wrote than an item from a menu. Controllers have a dynamic, physical relationship to the strips and with each other" (Mackay et al. 1998: 4).

A prototype of this type consists of the Strip'TIC, a tool that allows the display and use of augmented paper with a digital pen. The system that transforms strips from simple paper to increased stripes consists of a vision-based tracking component, an augmented rear and a front projector. The objective of this prototype is to understand and evaluate the role of the tangible component of FPS and its physical manipulation, also by observing the methods of information annotation on strips in the execution of control tasks.

The researchers followed a participatory design process consisting of several phases of prototype development iteration, during which end users were involved from the first design steps. This approach allowed to improve the prototype, to make the changes requested by users and to integrate them taking into consideration the potentialities of the technologies in use. From the interaction phases, for example, it emerged that the controllers preferred to have the possibility to interact with the Strip'TIC not only with the digital pen but also with the finger touch directly on the instrument. This observation was considered and the finger touch was integrated into a later version of the Strip'TIC, consisting of a multi-touch interface capable of creating a multimodal interaction that brings together the traditional use of the instrument with an interaction with digital objects. The goal of the prototype was to evaluate whether the use of multiple interactive modes could overload and/or confuse the controller. As Savery et al. describe in their article, the tool is a multi-touch table top the controllers interact with a digital pen; this interface implements Augmented Reality instrument and potentialities to create a multimodal interaction which mixes traditional techniques with digital interaction. The tangible characteristic of the interface gives the user the possibility to directly manipulate real physical objects, obtaining an immediate haptic feedback. In addition, tangible interfaces give persistence and make the physical and digital domains communicate between each other's. More specifically, the augmented component detects the input of the tactile or pen-mediated interaction on the strip that can be a paper or a digital tool; while the digital part of the system locates the FPS and supports the controller in their organization providing on the basis of aircraft schedules.

Furthermore, it allows an interaction of three different types: i) touch; ii) with the digital pen; and iii) with physical paper objects; this interaction has been analysed with the end users who have been proposed to perform different tasks, each of them with the use of the three different interaction modes. The results showed that the different modalities do not confuse the controllers, who tended to differentiate the modalities according to the tasks; moreover, the differentiation is constant during the controllers' performance, in fact they adopt "per for writing on strips, touch for selecting strips and flight levels and paper for arranging the flight strips on the strips board" (Savery et al 2013: 19).

The body interaction and the use of the FPS have been analysed in the phases of explorative design of multimodal solutions for remote control (Chapter 4); in addition another inspiring element encountered in the following projects is the end-users involvement, which is considered paramount for an efficient design of tools to be introduced in a complex environment as the Air Traffic Control is. In regard to the end-users contribution to the design of new technologies, as Mackay et al. noticed "Air traffic control is understandably conservative, since no one wants to reduce safety"

(Mackay et al 1998: 4), on the other hand ATCOs are generally open-minded toward the introduction of modern systems able to support them in facing the ATC complex and variable scenario with an ever-increasing traffic levels.

Chapter 3

Remote Tower Control

3.1 The Out of the window tower control

The Air Traffic Control (ATC) is a service provided by air traffic operators who manage the flights on the ground and in the airspace, with the primary scope to guarantee a safe, expedite and efficient flow of traffic and to prevent potential collisions. The service can be also provided to military, private and commercial aircraft flying in the airspace and based on the kind of flight, the Air Traffic Controllers (ATCOs) furnishes instructions, which are more mandatory than the flight information that a pilot can also decide to disregard. In order to avoid incident and/or accident, the ATCO manage the traffic separation process that allows the aircraft to maintain a minimum distance among them; in addition to the ATCO support, the airplanes are equipped with the collision avoidance systems that warn the pilot in case another vehicle is too close to risk a collision.

The focus of the PhD was on a specific area of the ATC, namely the Aerodrome Control executed by operators in the Tower Control building, the Tower ATCOs, who authorize (or not) the aircraft, vehicles and people movements on the runway(s) and taxiway(s) ensuring that the minimum separation is respected in the area under his/her responsibility. This area is called manoeuvring area and it is composed of the runways, the taxiways and of the airspace around the airport within the range of 8 km (5 nautical miles) and until 700 meters (2000 feet) above sea level. This part of the airspace is called the Aerodrome Traffic Zone (ATZ) and inside this space, all the vehicles, people and aircraft must contact via radio communication the Tower ATCOs in order to ask for the permission to move.

ICAO 9426 Air Traffic Services Planning Manual is stated that an airport control tower must fulfil two main operational requirements:

a) "the tower must permit the controller to visually survey those portions of the aerodrome and its vicinity over which he exercises control;

b) *The tower must be equipped so as to permit the controller rapid and reliable communications with aircraft with which he is concerned.*" (ICAO 1984: 1)

In the ICAO document it is also affirmed that the controller must be able to distinguish between airplanes and between them and other vehicles during their operation on the manoeuvring area. The most important aspects influencing the required visual observation are the siting and the height of the control tower building. The optimum tower site will normally be part of the aerodrome, provided that at the intended height of the tower structure does not become an obstruction or hazard to flight.

The airport control tower is usually a windowed structure, which might be as close as possible to the centre of the manoeuvring area, approximately in the middle of the runway or in the nearness of the runways intersections, if there is more than one runway. In the tower, the ATCOs manage the traffic through visual observation, giving permission for the movements in the ATZ and, if necessary, they also provide information on the planned traffic around this area. Moreover, the Flight Information Service and the Alerting Service are furnished by the ATCOs to the airspace users.

In summary, the main functions of TWR ATCOs are:

- To control of the immediate airport environment through a visual observation;
- to guarantee the separation and efficient movement of aircraft and vehicles on the manoeuvring area;
- to manage of aircraft in the air near the airport;
- To communicate with, coordinate and update the other control areas.

3.1.1 Roles and responsibilities

In order to give an overview of the roles and responsibilities in the Aerodrome Control, the main operational working areas are described in the following paragraphs, bearing in mind that each tower might have specific procedures depending on the complexity of the environment, which can be determined by the traffic density and the number of runways. Generally speaking, the three above-mentioned areas are: tower control, ground control and clearance delivery/flight data. Additional roles can be implemented in larger airports, like the Tower Supervisor and Approach Controller; others can be merged based on the size and movements at the airports.

Clearance Delivery

The primary responsibility of this position is to guarantee that the aircraft receive correct aerodrome information, as weather and airport conditions, and to issues the route clearances to the airplanes, usually before the phase of taxing that means before the aircraft leaves the parking area to go to the runway for the departure. The route clearance reports the details on the flight path that an aircraft will follow after the departure. This information is also communicated to the flow control unit and ground control to ensure that the time restriction, furnished by the relevant unit, is respected by the aircraft during the movements on the manoeuvring area. Moreover, the ATCO fulfilling this role ensures also that the (Electronic) Flight Progress Strips are correctly and coherently generated and s/he coordinates with the Ground and Tower Controllers. Additionally, among his tasks there are also the update and monitoring of the Flight Plan data and if necessary, of the Flight Progress Strips. The coordination is a fundamental part of this position, in fact at busy airport it is also called Traffic Management Coordinator (TMC) or Ground Movement Planner (GMP), as s/he could be in charge of the aircraft push-backs planning especially at heavily congested airports, in order to avoid taxiway and apron gridlock.

The clearance delivery is routinely merged with the flight data position, which provides controllers and pilots with the most updated information on weather changes, runways closures, ground delays at the airport and etc. This task is frequently performed by means of a recorded loop on an established frequency: the Automatic Terminal Information Service (ATIS).

In case an emergency occurs, the Coordinator controller is responsible for the communications expected to be activated during alarming, emergency and accident situations and he/she also provides all the assistance to the Tower Controllers involved in the management of the emergencies.

Ground (GND) Control

This position manages the movements on all taxiways, inactive runways, parking zones and intersections where the aircraft arrive and also sectors not released to the airlines or other users, with the exception of the active runway(s). Moreover, the Ground controller monitors and updates the Flight Plan data through automatic systems; switch on/off and adjusts the visual support systems; s/he also updates, if necessary, the Flight Progress Strips and he/she is responsible for the air traffic management on a specific frequency, in coordination with the clearance delivery operator.

If an emergency occurs, the Ground controller stops all moving traffic and coordinates with the Crash Fire Response (CFR) as well as with the Tower Controller. The coordination with the Tower Controller is foreseen also in case of runway crossing (aircraft and vehicles). In case of bad visibility, the Ground Controller activates the related restrictions in accordance with the weather conditions. For example, in case of no visibility on the parking area, the Ground Controller authorises only one aircraft to go to the runway if multiple vehicles from the same area make the same request. Among the tasks of the Ground controller, there is also the provision of the weather information, together with the updated value for the QNH[6] and other data, which is considered useful before taking-off, landing and during the first radio communication for a safe and efficient conduct of the flight.

The communication with any aircraft, vehicle or person walking or working in the area under Ground controller responsibility must ask for clearance to the him/her. This is usually done via radio frequency, even if there might be specific cases where other procedures are used. When airplanes and other vehicles don't have any radio communication systems, they must follow the operator's instructions through aviation light signals or ask for the support of other vehicles with radios. In regard to the communication with people working on the airport surface, a communications link is used in order to be in contact with ground control, normally performed by handheld radio. The position of the Ground control is fundamental in the sequencing of

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[6] QNH is a code indicating the atmospheric pressure adjusted to sea level.

departure airplanes and they have a high impact on the safety of the overall operation.

Tower (TWR) Controller

The main responsibility of the Tower control operator is to give the authorization for all airborne traffic arriving, departing or overflying and to monitor that the separation between the aircraft on the runway is always respected. S/he is also in charge of all the air traffic in the Aerodrome Traffic Zone (ATZ) in line with the current procedures and regulations; in addition the tower operator must ensure that the vehicles use the correct runways, that unknown traffic does not enter the control zone, and s/he has to coordinate the vehicles on the runways in case of inspections or maintenance activities. During runway incursions the Tower controller can also monitor the safety warning systems used to notify the operators in case of any potential risk on the runway(s).

There are some cases in which if there is an emergency and the minimum separation could not be assured, the Tower controller can instruct the aircraft to "go-around", which means that the airplane could not land and it has to fly around the airport in a specific circuit, until the clearance to land is given. One vital factor for the efficient execution of the tower control is the coordination between the ground and the tower controller. In fact, the former must keep aware the ground controller of any operations which can have an impact on the taxiways and, meanwhile the latter must communicate with the tower controller all the traffic on the taxiway that will affect the movements on the runway(s), in order to sequence an expeditious traffic flow.

In case of Runway Crossing, the Tower controller coordinates with the Ground controller to issue runway crossing clearances (aircraft or vehicles).

In addition to the ground controller, the tower operator coordinates also with the clearance delivery position, the approach control and the Tower supervisor in case a runway change is necessary.

As the ground controller, also the Tower position is in charge of providing pilots with weather information, with the updated value for the QNH before taking-off, landing and during the first radio communication and, he/she always provides the last updated data regarding the wind on the ground, when giving the clearance to take-off/landing.

Moreover, also the Tower controller normally updates the Flight Progress Strips (FPS) for the areas under his/her responsibilities and assists aircrafts in emergency situations.

3.1.1.1 Controller support systems

The ATCO uses several devices and systems to provide the Air Traffic Service (ATS) and has already stated in the previous chapter, the main source of information is the visual observation, which is performed directly looking “Out-The-Window” (OTW). In some not insulated tower, the sound of the aerodrome (e.g. engine noise, birdsong, wind noises) is directly received from the outside environment through the tower building. Other functions and/or systems that are used by the operators for the execution of his/her tasks include:

- **Voice communications systems**: the ATCOs use the microphone mainly for the communication with pilots, and the telephone if they have to coordinate with other airport entities or authorities;
- **Flight Data Processing Systems**;
- **ATS message handling ability**;
- **Manoeuvring of Aerodrome Ground Lighting (AGL), navigation aids and Instrument Landing Systems (ILS);**
- **Warning systems and additional sensors** (e.g. radar information);
- **Air and Ground Situation Displays**: the air situation display is actually used to see the traffic around the area of interest, while the ground situation display provides the operators with the view of the runways and taxiways.
- **Binocular function**: this function could facilitate the operator(s) when s/he needs to look more closely at objects in his/her field of view. The operator(s) could also have the possibility to angle the view and zoom into objects.

During their job, the tower ATCOs use a number of systems which can be slightly different from tower to tower. This is the case of the (Electronic) Flight Progress Strips, which can be paper or electronic strips and they are used to track an aircraft in the ATZ. On the strips there is information on the aircraft as its flight number, the altitude, the departure and the destination and they allow to the ATCOs to have a clear understanding of the traffic around the aerodrome. The paper strips are placed in a strip bay with other and their different colors and positions in the bay indicate specific information about the flights (e.g. arrival/departure aircraft).

Other systems are the surveillance displays, available to controllers at the bigger airports and the radar system called "secondary surveillance radar" that shows a map of the controlled area, the position of airplanes and some information related to the aircraft, as speed and altitude. During adverse weather conditions the tower controllers could use also other types of radar, as the surface movement radar (SMR) and surface movement guidance and control systems (SMGCS) for a more efficient and safe control of the traffic.

There are a wide range of capabilities on these systems as they are being modernized. Newer systems include the capability to display higher quality mapping, radar target, data blocks, and safety alerts, and to interface with other systems such as digital flight strips.

3.2 A new operational concept: the Remote Tower Operation

The concept of Remote Tower Operations (RTO) refers to an operational concept that enables the cost effective provision of Air Traffic Services (ATS) at one or more airports from a control facility that is not located in the local ATS Tower. Each operator will have a Controller Working Position (CWP)[7], including all the necessary systems for the remote provision of ATS.

The operational modalities of the Remote Tower are different from the traditional

[7] the operator (ATCO / AFISO) work station including necessary ATS systems

ones, starting from the replacement of the onsite view of the airport with a visualisation system placed in multiple locations of the remote airport, which using high resolution visual and infrared (IR) cameras and sensors, shows a virtual picture of reality to the ATCO.
The Single European Sky ATM Research (SESAR) program has defined three different operational types of remote virtual tower:

- **Single Remote Tower:** One air traffic controller is responsible for operations at one airport at a time.
- **Multiple Remote Tower:** One air traffic controller is responsible for operations at more than one airport at the same time. This concept is completely new compared to current operations. This mode depends very strongly, if not more so that the other two modes, on operational context and as such it is likely to coverage a wide range of different environments and operating methods.
- **Contingency Tower:** A contingency facility to be used when an airport tower is unserviceable for a short period of time (e.g. fire, technical failure). Remote Tower operation will then assure at least a basic level of service.

For the research purposes of the PhD, only the Single and Multiple Remote Tower configurations have been considered and analysed during the activities described in this thesis.
The main target for the Remote Tower Concept is low to medium density rural airports, which today very much are struggling with low business margins. A reduction in ATS costs for those airports is foreseen by introducing these concepts. On the other side, the main target for the Contingency Tower solution is medium to high density airports, whereas for most of them no real contingency alternative exits today, if the ordinary tower has to close down for any reason.
A preliminary operational concept was defined in the Remotely Operated Tower (ROT) project, led by LFV and Saab. This was further enhanced by developments made

during the Advanced Remote Tower (ART) project led also by LFV and Saab. Both projects investigated the feasibility of an initial concept and a set of technical enablers for remotely provided Air Traffic Service (ATS) to a single aerodrome.

Remote and Virtual Tower was first proposed for development and assessment in some projects funded by SESAR, whose aim was to define and then mature the Remote Provision of ATS against the three identified modes (Single, Multiple, Contingency). At the time, the project was largely focused on the north European environment where the main driver was cost efficiency for low complexity, low traffic aerodromes.

As the above-mentioned projects reached completion and many aspects of the concept have been matured through learning and validation, it has become clear that the original definition of the concept and classification according to simple modes of operation was not sufficient. However, the projects acknowledge that there is still much to learn on the subject and this will require development and assessment in future projects.

The motivation of the growth of this new concept is the current European situation of small and medium density airports that often have to face the difficulties and the high costs for the provision of a safe and efficient Air Traffic Service (ATS). Many of these airports act as public service routes for isolated communities and their importance is increasing with the expansion of low-cost airlines; for these reasons, in order to avoid the risk of closed down these airports and with the aim to maintain an adequate level of safety and efficiency, several European countries are in process of developing remote tower management for small and medium density airports.

The focus of the concept is on reducing the cost of providing ATS without reducing the level of safety. The reason for this primary objective is in response to a need to reduce the cost of ATS provision generally but with a particular focus on less financially secure aerodromes.

The current costs associated with the provision of ATS are high and need to be reduced, particularly at low to medium density airports. The high costs are then passed onto the customer through increased aerodrome/landing fees, which in turn result in higher airfares and lowers the propensity of customers to remain users of aerodromes. It is necessary to maintain commercial air traffic services at small and medium density airports, as many of these routes act as public service routes.

A large proportion of the ATS costs are associated with the building maintenance and upkeep of the physical ATS facilities and the costs of personnel to provide the ATS. The maintenance and upkeep of older tower facilities can be inefficient and expensive, aging equipment and infrastructure to maintain. Unique competences are required for maintenance and components can be difficult and expensive to repair when they fail. Construction of a new aerodrome control tower would be very expensive and disruptive to operations and hence is not a viable option for less financially secure aerodromes ATS systems, equipment, specific operating methods and procedures currently vary according to aerodrome. Cost inefficiencies relate to equipment and systems as well as to the training of controllers (methods, equipment and procedures).

The Control Working Position (CWP), provided in many local towers particularly at smaller less financially stable aerodromes is often deficient in space and in consideration for human performance features/elements that should be incorporated into modern day CWPs and the set-up of required equipment.

Local facilities sometimes are required to remain open and staffed all day despite perhaps having only a sparse number of flights. This again contributes to rising costs and efficiencies for the aerodromes, aerodrome operators and ANSPs.

3.2.1 Single Remote Tower

The concept of Single Remote Tower foresees the remote provision of the Air Traffic Services (ATS) defined in ICAO Air Traffic Services Planning Manual and EUROCONTROL Manual for AFIS for one airport at a time from a remote location, instead of a control tower local to the aerodrome. The ATS will still be provided remotely by an Air Traffic Controller (ATCO) or by an Air Flight Information Service Operator (AFISO), thus meaning that the full range of ATS will be part of either of the two main services of TWR or AFIS.

It is expected by the aviation community that the overall ATS will be provided without provoking any negative impact on the airspace users, if compared to local provision of ATS. The impact on the airspace users will be dependent on some factors as the coverage of the visual presentation, the distribution of the traffic and on the needs of the single aerodromes and local implementations.

The target environment, where the remote provision of ATS for a single aerodrome (Single Remote Tower) is expected to be applied, are small airdromes with low density traffic (mostly single operations, rarely exceeding two simultaneous movements), as well as some medium traffic density airports (possibility of more than two simultaneous movements). In the long-term, this concept might be expanded and applied also to larger airdromes or small airports which occasionally experience more traffic density (e.g. tourist aerodromes and/or remote airports during a particular event etc.). In addition, this configuration could be used by bigger aerodromes with multiple runways, in order to offer the ATS service as the airport expands.

The following chapters describe the key parts of the remote provision of ATS, whose many elements and functions will remain the same when provided remotely, as if they were provided locally.

With regard to the changes that the new concept will produce, the most evident is that the ATCO will no longer be present at the aerodrome under his/her responsibility, but from a remote position which at the moment is expected to be a biggest airport, but it is not excluded that "the ATCO or AFISO [...] will not necessarily be located at the aerodrome." (OSED 2015: 36)

A second consequence of the changes of the new operating methods will be the substitution of the direct "Out-The-Window" (OTW) view of the aerodrome with relayed visual presentations.

The only aspect relating to the ATS that will change is the manner in which the service will be offered; while, as already said the kind and set of services will remain the same as those currently provided locally.

Additional changes will interest technologies and devices that will support the ATCO in performing their tasks. In the OSED, a series of suggestions are given in regard to examples of future supporting tools, leaving also the possibility to the technological exploration, due to the fact that the remote control is a new, relatively young research field and to the existence of the airports different needs.

In regard to the local tower building, it could be removed, as well as all the maintenance services and infrastructures, and they will be substituted by other systems and sensors installations that will be managed by central maintenance teams. Another hypothetical solution is that multiple single remote tower would share a remote location with other airports, in order to decrease the costs of the whole system and ensure an efficient service.

3.2.1.1 Single Remote Tower Module (RTM)

From the point of view of the working environment, it is expected that the remote provision of ATS will be provided from a Control Working Position (CWP), which together with the visual presentation of the airdrome, is called Remote Tower Module (RTM). The RTM may be located anywhere (i.e. on or off aerodrome site). However, to capitalise on shared infrastructure and economies of scope, the RTM may be located in a Remote Tower Centre (RTC).

Multiple operational configurations are foreseen for the RTM, independent of the number of aerodromes under the ATCO control and of the visual presentation level of detail. Here below a list of possible configurations is provided, as described in the OSED D35.

- **RTM 1**: one CWP equipped with its own dedicated set of screens for visual presentation (CWP 1);
- **RTM 2**: one CWP with two positions (CWP 2) that share the same visual information. In this configuration, there is the possibility to place an additional role (e.g. a supervisor or a second operational controlling position);
- **RTM 3**: two CWPs (CWP 3 and 4) where there would be a shared service

provision to one aerodrome (as in RTM 2 if the two positions are used). In RTM 3 each position has its own screens for the visual presentation and the two CWPs might have the same or different aerodrome view. This configuration could also be utilised for the provision of an ATS to two individual aerodromes, with the CWPs independent from each other and utilising half of the RTM;

- **CWP 5**: A position without screens for visual presentation (CWP5). This set up would be used for roles where the view of the aerodrome is not required (for example, approach or supervisor) but other surveillance system would be possible required.

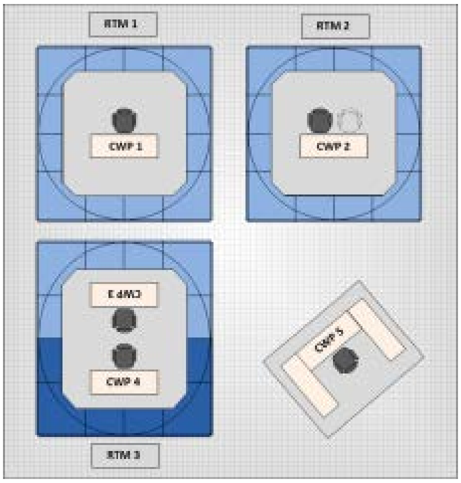


Figure 6 – Potential configurations of the RTM (OSED 2015: 45)

In addition to all the above-mentioned configurations, the Remote Tower Modules could be applied in a local aerodrome tower, with the aim to offer "blind spot coverage or additional view points for working positions" (OSED 2015: 45). This position could consist of a smaller CWP in multiple configurations.

There are still no standards on the RTM set up and each of them may be configured differently to fulfil the local requirements and based on the technical solutions applied. Nevertheless, it is expected that the use of standards for the support systems that take into consideration Human Machine Interface (HMI) aspects would be preferred, in order to improve the benefits on a wider scale. In this regard, in the OSED is stated that "The use of a standardised RTM solution will eliminate the many different HMI interfaces seen in operation currently. Interaction technology options may also be deployed on the user interfaces for more efficient and optimal user interaction." (2015: 45)

To better understand how a single ATCO could provide the ATS to only one aerodrome at a time, the following examples show some possible operating scenarios. In the examples, there are key summary information and a table presenting how the RTM and ATCO may be implemented and in which way the CWP configuration might change in relation to modifications in the traffic situation complexity.

Aerodromes	RTM required	ATCO/AFISO required	ATS provided to aerodromes in parallel	RTC supervisor	Traffic Coordination
1	1	1	No	No	No

Example 1 – Basic Single RTM (OSED 2015: 53)

This first operation scenario with a single remote ATCO, providing ATS from a dedicated location to a single aerodrome, is the simplest one. A single RTM is configured to provide ATS to a one nominated airport. In this case no other aerodromes are managed from this specific RTM.

Aerodromes	RTM required	ATCO/AFISO required	ATS provided to parallel aerodromes	RTC supervisor	Traffic Coordination
3	Max 2	Max 2	No	No	Yes

Example 2 – ATS to single aerodrome with traffic coordination (OSED 2015: 54)

In this second option two ATCOs share the control of three aerodromes and the RTM is configurable for each airport; in case there is the necessity of managing the traffic to a third airport, the former might be open but without the provision of any Air Traffic Service.

However, the above-mentioned scenarios have been designed for aerodromes with relatively low traffic density.

3.2.2 Multiple Remote Tower

The Multiple Remote Tower has the aim to provide the ATS to more than one aerodrome simultaneously. In this case, as for the Single Remote Tower, the overall ATS should be provided without negatively impact on the air traffic and airspace users and it should guarantee an acceptable level of safety and efficiency. Nowadays the management of multiple aerodromes by a single ATCO does not exist. The difference between the new and previous operating methods, in addition to the differences already described for Single Tower, is mainly concerned with the ATCOs ability to provide ATS to more than one aerodrome in parallel. This concept can be applied to low and medium density aerodromes, where simultaneous movements can occur; while it is not considered for larger aerodromes with multiple simultaneous movements.

In traditional operations, the Instrumental Flight Rules (IFR)[8] traffic is usually planned in advance, while Visual Flight Rules (VFR)[9] flights can provide a flight plan in order to give the ATCOs the possibility to know their presence in the traffic flow. If they don’t communicate the flight plan this can give less advanced notice of their operation to the ATCO, who will have to manage VFR in the already planned IFR flights, operating strategically and tactically in order to organise an efficient and safe traffic. In the case of multiple remote tower, an advanced coordination between the actors of the airspace would be necessary and for the IFR flights this process could take place at the moment in which the schedule timetables are approved; while for the VFR flights, it could be done on a daily tactical basis by the supervisor of the Remote Tower Centre (RTC). It is also foreseen that “The same procedures could take place in the case of revised arrival/departure times (most common cause of delays).” (OSED 2015: 52).

[8] Rules and regulations to be applied when outside visual references are not sufficient for the safe conduction of the flight.
[9] Rules and regulations that govern flight operations when the general good weather conditions and visibility allow the pilots to see where he/she is going.

Although it is not possible to have an accurate prediction of the flight movements, this kind of coordination could be useful to be aware of the aerodrome traffic with a certain advanced timeframe, as for example in a period between 30 and 60 minutes. The cooperation in planning the flight is considered a factor able to increase the ability to provide ATS service to multiple airports in parallel.
Aircraft declaring an emergency are considered outside of this planning process as they will be given priority and the other flights will have to be diverted and/or delayed.

3.2.2.1 Multiple Remote Tower Module (RTM)

The operation methods of the Multiple Remote Tower depend on several factors: some are in common with the Single Remote Tower, while others are peculiar to this modality.
With the Multiple Remote Tower there would be different configurations depending on how many aerodromes the ATCO has under his/her control; the general principle is that one ATCO will provide the ATS from one RTM at least to two aerodromes in parallel in a configuration 1:2. Other possible options would be the configuration 1:3 or more, depending on various factors, among them there could be the peak hour traffic level, the technical configuration of the RTM and the intersections between the traffic schedules at each aerodrome.
In order to provide different aerodrome with the ATS, if the RTM is a part of a wider RTC set up, it is expected that the aerodromes management in a Multiple RTM will be flexible. The possibility to have a RTM inside a bigger RTC facility is considered that "would also enable operators to be able to reduce the number of aerodromes if required." (OSED 2015: 47).
The Operator(s) could switch the control from one aerodrome to another in any moment s/he has to provide ATS to those airports under his/her responsibility. In regard to the simultaneous control of more than one aerodrome, the OSED suggests that "The use of collaborative planning and/or traffic coordination would increase the ability of a single ATCO/AFISO to provide ATS service to multiple aerodromes in

sequence.” (OSED 2015: 38).
Moreover, the ATS and airspace interesting an aerodrome will be organised taking into consideration the departure and arrival flights and the Air traffic Control Centre (ACC) will be able to always inform pilots about the status of the airspace and of the service provided.
From the technical point of view, in the OSED it is stated that during the provision of the ATS under the Multiple Remote Tower configuration, it is important to consider sharing or duplicating “certain features required for the provision of ATS to more than one aerodrome.” (OSED 2015: 47).
Some of the above-mentioned features are:

- Communications;
- radar displays;
- flight strips;
- Other functions with different integration and sharing degrees between aerodromes, depending on the requirements of the situations and of the operations.

In addition “Any duplication of equipment/features that occurs in the RTM may be accompanied by distinctive features to allow easy and instant recognition of the aerodrome the feature relates to.”(OSED 2015: 48).
In this case, as also for the Single Remote Tower, the visual presentation is considered fundamental to provide the ATS and to allow the continuous monitoring of each airport and it shall show the view of the area of responsibility in line with the regulation. In order to gain this objective, the displays of each aerodrome will be continuously and simultaneously showing the images of the aerodromes under ATCO control. A fundamental requirement is considered the possibility to distinguish at all times the aerodrome under control and which displays and/or other systems relate to a specific airport.
Moreover, in the OSED it is suggested that the layout of the screens shall enable the simultaneous control of the aerodromes and their configuration will also be dependent

on the number of airports being managed.

Additional guidelines for the displays are that the ATCO should have the possibility to switch from one aerodrome to the other, in a way that s/he could change

> "*the number of screens each aerodrome is displayed on or the view provided of each aerodrome. When providing a visual presentation of multiple aerodromes one or more of the displays may be subject to a degree of compression (where the visual image is compressed to fit in a small area, without reducing the viewing angle covered by cameras/sensors).*" (OSED 2015: 48)

The ATCO could also have the possibility to hide the screen when not needed and be able to easily come back to the hidden visualisation when his operation is required. This kind of interaction should foresee additional specifications in order to maintain an acceptable level of performance of the ATCO and of the safety of the whole operation.

From an operational point of view, it is expected that a key factor in determining the controller's possibility to improve the number of aerodromes under his/her control would be the number of simultaneous movements (aircraft and other vehicles) and the number of movements per time frame at the involved airports. The number of parallel movements, which could be a reference for the increase or decrease of the aerodromes managed by the operator(s), has not been defined yet. In order to give an idea of the concept, the figure below can visually explain the ATCO's capacity in controlling five airports in parallel.

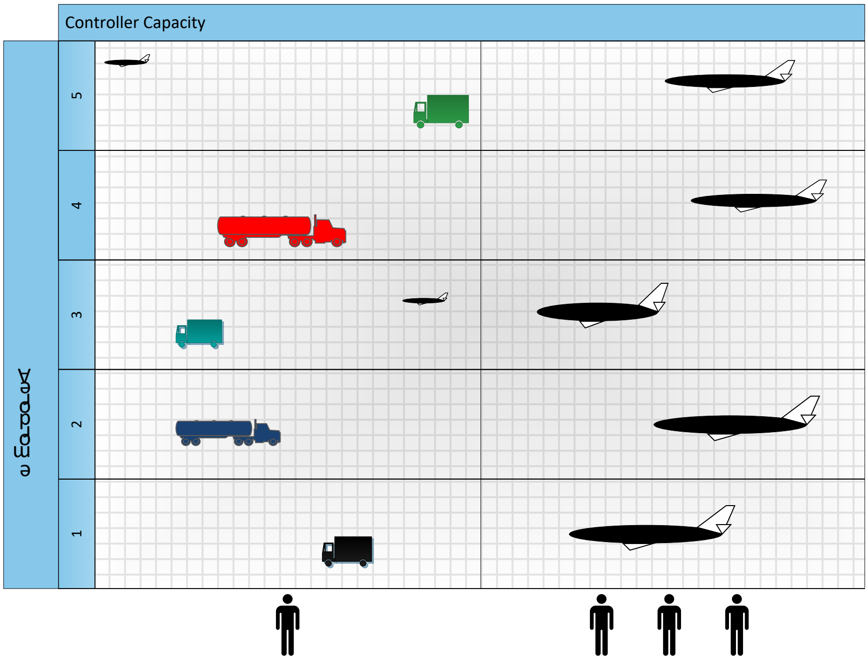


Figure 7 – Controller Capacity (OSED 2015: 49)

On the left column there are only ground vehicle movements and/or possible overflights, this situation is considered in line with the ATCO capability and ability to manage the traffic. On the other column, the right one, the same five aerodrome show departure/arrival movements, that an ATCO is not considered to be able to handle simultaneously. The same statement is valid also if the movements per hour overcome a certain number, which has not yet been established, as it will depend on how many aerodromes are under ATCO responsibility. In order to face this aspect, in the OSED the following solutions are proposed:

1. *"The traffic is sequenced in such a way that aircraft / vehicles are handled one at a time;*
2. *Traffic is generally reduced during preplanning;*
3. *The number of ATCOs/AFISOs is increased;*
4. *Tasks are outsourced (e.g. ground control is executed by a dedicated additional Controller) in order to provide the ATCO/AFISO load relief."* (2015:

48)

The objective of the proposed solutions is to give the ATCO the possibility to provide the ATS service in parallel in multiple ways, always maintaining the view of the aircraft and of other vehicles, ensuring the safety of the operations.

The ATCO could provide ATS to multiple aerodromes in one of the following ways, as illustrated in Figure 6 (with detailed descriptions provided overleaf):

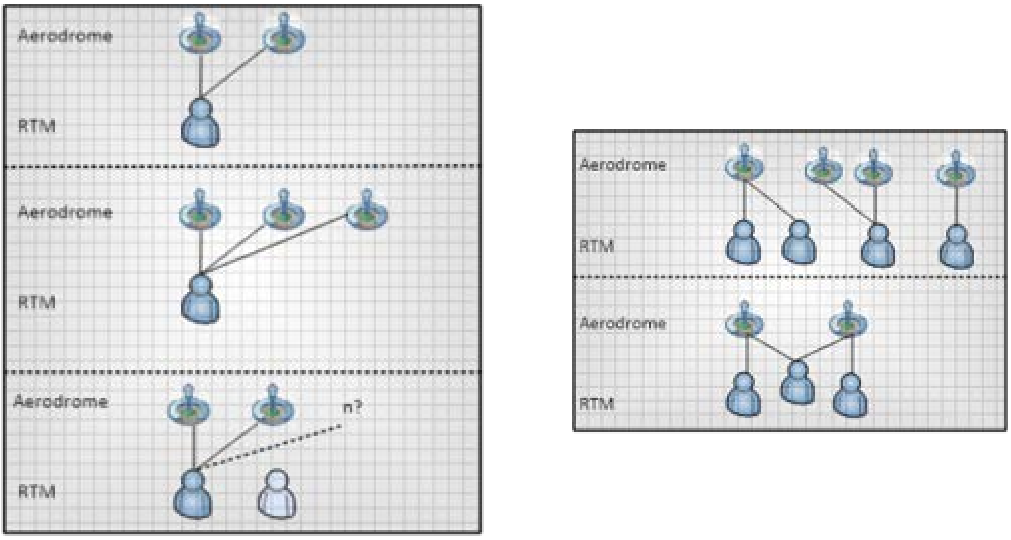


Figure 8 – RTC to aerodrome mapping (OSED 2015: 49)

Two aerodromes (1:2)

The traffic demand at certain aerodromes might be of such composition that the ATCO is restricted to the control of two aerodromes and is capable of managing both aerodromes simultaneously. Thus several movements at both aerodromes might be executed in parallel.

Three aerodromes (1:3)

In this configuration an ATCO is expected to have the visual presentation of three airports, with the possibility to enlarge the primary airport managed with the remaining ones either displayed on a presentation equal in size or on smaller periphery screens. For this configuration it is foreseen that a supervisor role could be necessary to support the ATCO during his/her task and reduce his/her potential high workload.

Numerous aerodromes (1: n/many)

In this case, the same principles are valid as for the configuration 1:3, of course with the provision of additional control tools, related to the management of the additional airports. In those occasions in which the traffic may increase, there would be also the possibility to introduce the supervisor role in the airport management process in a 2-to-many (2:n) positions. With the support of an additional role, the multiple control might be better organised and managed. Meanwhile in case of multiple small and quiet airports, they could be merged in one RTM until the traffic density increases.

In addition to the supervisor, also additional operators might be required in emergency situations or in period of high traffic level, even if this option is considered not to be frequently applied, as the remote control concept refers mainly to small and medium airports.

No use of visual presentation

In the concept of multiple remote tower operations, it is being considered also the possibility to provide the ATS service without the implementation of a visual presentation. This is the case of airport where for a long period of time (e.g. 1-2 hours or more) no movements are scheduled. The ATCO would continue monitoring the airport in case of incoming flight and s/he will give the clearance to vehicles on the runways and taxiways via Radio Telephone (R/T) and surveillance aids.

In regard to this kind of provision, the use cases considered in the new concept are the following:

1) *"In a 1:n set-up, as the redundant screens could be used to give a wider visual of the remaining aerodromes.*
2) *It would also be used at the wider RTC level to merge RTMs. Quiet aerodromes could hence be merged into existing RTMs at certain periods of the day. The RTM increasing from a 1:3 to a 1:4 relationship RTM."* (OSED 2015: 50)

Moreover, this configuration is expected to be applied only in the period of zero scheduled traffic and for those aerodromes that before the introduction of the remote tower already had an advisory service.

3.2.3 Remote Tower Centre (RTC)

With the new concept of Remote Tower Operations, it has been introduced also the idea of a Remote Tower Centre (RTC). It would consist in a centralized facility where more than one Remote Tower Module could be located. The aim of the RTC is to increase the benefits of the RTO and maximize the cost effectiveness “due to economies of scale brought about through increased sharing.” (OSED 2015: 50).

The RTC principles would not be dependent on the kind of concept application, thus both the Single, Multiple and Contingency concepts can be implemented in the centralized facility. One of these principles would be that the RTC shall be flexible and applicable to multiple configurations of the RTOs concept and the characteristics of the centralized facility shall not be prescriptive for all the RTCs.

As previously stated, in an RTM a single ATCO can manage one or more aerodromes in parallel and depending on the density of the traffic, the number of airports can change, some could be closed and other could be merged. In addition to the traffic density, the airports could be merged based also on other factors, as the ATCO license and/or technical possibility to add new aerodromes to those already under control.

With regard to the number of the RTMs that could be placed in an RTC, the following factors must be considered:

- Number of aerodromes to be connected to the RTC;
- Maximum parallel movements possible for each ATCO in an RTM;
- Ability to relate RTM and aerodromes;
- Implementation of additional or spare RTMs for contingency situations, depending on RTCs.

In order to improve the benefits of an RTC, it is suggested that the operators in an RTC would be licensed for each airport they have to manage. This aspect will also depend upon the size of the Remote Tower Centre.

The following image provides an overview on the RTC layout.

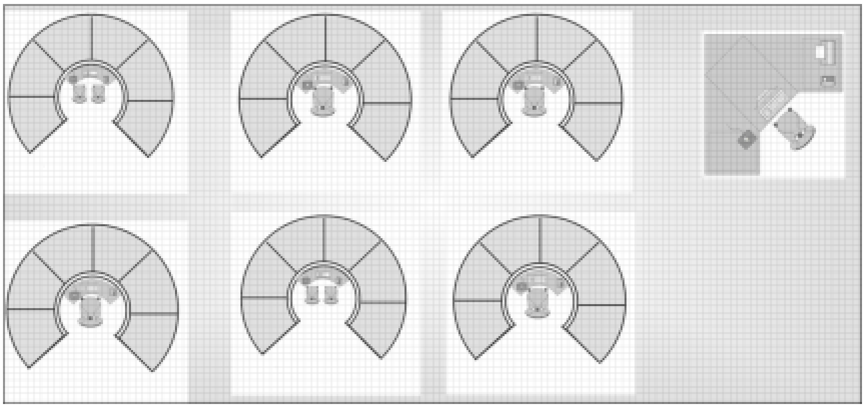


Figure 9 –RTC layout (OSED 2015: 50)

The concept of the RTC foresees that some of the RTMs within the facility might be used to provide ATS during Multiple RTOs and in these cases the airports under control would be categorized in clusters or sub-sets of them. The classification could be under the responsibility of the RTC supervisor and it will be based on the following factors:

- **Location:** aerodromes of the same geographic area or included in the same controlled area are clustered;
- **Size:** large airports are included in smaller clusters and small aerodromes are more often in the same large clusters. Otherwise, bigger airports and much smaller ones are grouped together, in order to have a more balanced traffic;
- **Traffic peaks**: airports interested by overlapping traffic peaks are not grouped so to avoid the eventual increase of the controller workload;

- **Runway layout:** aerodromes with different runway numbers and/or direction are in the same set, in order to limit the possibility of confusion and/or error making.

The above-mentioned classifications could be also mixed in order to have different clusters, maintaining always a high level of efficiency of the ATS provision and of operations safety. In the following figure, some examples of clusters classification for one Remote Tower Module are provided.

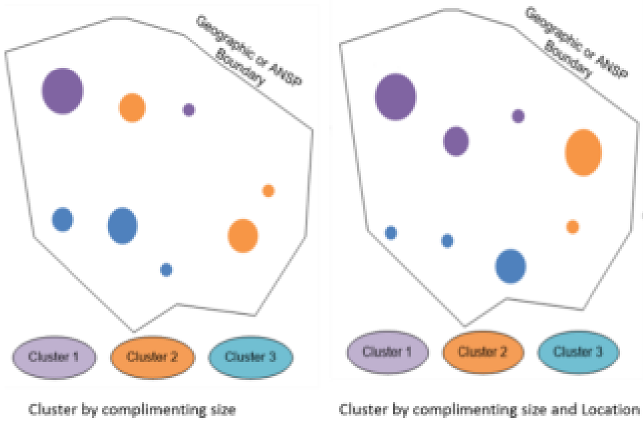


Figure 10 – Examples of airports clusters for one RTM (OSED 2015: 58)

3.2.4 Single and Multiple Remote Tower

The Remote Provision of ATS features technical supports for the Air Traffic Controllers, both for the single and for the multiple remote tower operations. In the OSED technical requirements and devices to be implemented in the CWP are described. Some of them are related to the Single RTOs, other are communal to both single and multiple RTOs. All the systems that will be used in the new operational concept must be certified and the achieved ATCO situational awareness when using these systems will be measured, in line with the requirements of the operational environment. As the environments could potentially differ, multiple certifications will be necessary for operations with a specific service provider, in a specific operational environment. Thus, at least in a first phase, each technical implementation will have a local certification that could not be universally used.

The following sections introduce the technical systems and elements suggested for the performance of RTOs, as foundations for the overall concept independently of a precise operating method.

3.2.4.1 Roles and responsibilities

The concept of Remote Tower Operations will primary impact on the Air Traffic Controllers, together with the officers of the local airport. As previously stated the changes will not interest the overall roles and responsibility but some changes could occur on the modalities in which the ATS will be provided and, in addition, some tasks could be added to the traditional ones or be delegated to other roles, as the local agent (e.g. airport/rescue crew) or to new one, as the supervisor. This new role could be performed by an ATCO or a different position and s/he would be responsible for the overall management of the activities carried out in the Remote Tower Centres (RTC). A similar role is that of the Approach supervisor, who is in charge of the Operations Room, where the Air Traffic Controllers manage the en-route traffic.

The actors involved in the RTC should be up to three: ATCO, AFISO and RTC supervisor; they should not be all present at the same time and in the same RTC. The responsibilities of the ATCO would be to provide the ATS, while the supervisor in the RTC would be to plan the allocation of the RTM staff and in some cases to give support to the ATCO during the management of the traffic. In addition s/he may be in charge of the definition of the RTM configurations, as for example to merge airports in different RTMs based on the traffic conditions; it could be possible that a three-aerodromes RTM could become a two-aerodrome position, while the third one could be managed by a separate RTM. Moreover, this role could be performed by a specific person or by a shift operator (ATCO/AFISO).

The role of the supervisor could be performed by separate and extra personnel in charge of the overall management of the centralized facility and also the supervision of all the airports being controlled by the ATCOs. It could be introduced a dedicated CWP for the supervisor where s/he could organize all the administrative and planning issues, together with the management of the staff allocation and the monitoring of the technical systems in the biggest airport. In the smallest one, it is expected that the technical checking would be performed by designated technicians.

Moreover, in regard to the operators' positions, there could be the possibility to introduce an additional role in the RTC who could be in charge of some tasks, depending on the necessity of the ATCOs at each airport. The tasks could be the clearance delivery, the approach and/or the ground tasks, as well as the coordination management. This could be implemented in some configurations, as for example the 3:4 where two ATCOs are each providing ATS to two aerodromes, the additional controller may perform ground related tasks at all four controlled aerodromes.

The number of the operators and their shift period are expected to be decided taking into consideration the following aspects:

- Expected traffic density and peaks;
- Number of RTMs;
- Possibility to combine aerodromes in one RTM;
- Number of ATCO licenses;
- Requirements of the relief staff.

Among the tasks that the ATCO might not execute anymore there are "physical runway inspections, gathering MET data, answering public telephone calls directed to tower just by tradition" (OSED 2015: 81), which today are currently performed by the ATCO in some cases in traditional operational environments. Together with the introduction of new roles (e.g. the supervisor), there could be the case in which it will be necessary to implement the automation of some activities in order to guarantee an acceptable level of provision of the ATS.

In particular, one of the main changes will refer to the performance of activities that involve the airport, due to the fact that the ATCO will not have direct access to the physical environment as it is nowadays. In addition it might be necessary to introduce new layers of responsibilities for the reliance on technical aspects, as new equipment is expected to be introduced in order to support the ATCO.

Moreover, as in some airports the ATCO working in the tower building, namely Tower (TWR) ATCO, is in charge of also of the service offered by the Approach area, in the case of Single Remote Tower, the TWR ATCO could have both the role of tower and approach.

In regard to the AFISO role, for those airports where the service is mainly provided by qualified local agents (e.g. rescue team or aerodrome operators), it will be possible that there will be a dedicated AFISO providing the service in addition to the local agents, in order to increase the task redundancy and avoid potential risks.

With regard to the technical aspects, nowadays the air traffic provider or the airport authority are in charge of checking the equipment status, as well as the visibility from the tower building through the windows, and guarantee that there is an acceptable working level. With the remote towers, this task will still be under the responsibility of the local airport authority and/or the service provider.

3.2.4.2 Controller Tool Support

The suggestions provided in the OSED have been organised in the following paragraphs, in order to give a brief and clear overview of what it is expected for the future Remote Tower Operations. The information reported below has been taken into consideration for the process of concepts design (described in chapter 6), together with examples of use-cases listed in the OSED. What comes out from the OSED is the expectation that the new tools and devices for Remote Tower control will mainly focus on the improvement of visual presentation, even if there are guidelines also for the recording and sharing of data, for aerodrome sound provision, for the availability of meteorological information and for the use of air and ground radar.

The following list comprehends the controller support tools that should be implemented in the Single Remote Tower, but however they may of course be applicable for Multiple RTO as well.

- **Presentation and updating of flight plan and control data;**
- **Radio Telephony Communications (ground and air);**
- **Functionality for manoeuvring and controlling:**
  - Airport lights;
  - Signal Light Gun;
  - Navigation aids;
  - ILS;
  - Alarms and;
  - Other airport systems.

With regard to the Multiple Remote Tower Operations (RTOs), additional support tools may be introduced; here below some examples of those tools in the in the context of Multiple RTOs:

- **Integrated flight data processing systems (FDPS):** this system could consist in the integration of the flight strips of more than one aerodrome into one device, namely the Flight Data Processing Systems, where the strips have a different colour coding, depending on the aerodrome they belong to.

- **Indication from which aerodrome a radio transmission is received:** a tool with this function could highlight where a radio transmission is coming from. This could give to the ATCO the possibility to associate the source of the communication and the station calling.
- **Route planning:** based on the known traffic, the ATCO could use this function to calculate the most feasible route both for aircraft and ground vehicles in his/her area of responsibility.
- **Conformance monitoring:** this function is foreseen as a support to monitor that "the forecast route from the route planning function is complied with by the pilot / vehicle driver." (OSED 2015: 51). In case of a deviation, the ATCO receives a warning alarm and s/he can transmit the right instruction.
- **Conflict detection:** this function is suggested if conflicts arise, e.g. runway incursions and/or airspace violations. Depending on the kind of conflicts, a corresponding warning could be provided.
- **Voice recognition:** the recognition of the voice could be implemented or in terms of instructions the ATCO gives to the system which trigger following activities; or in terms of system recognition of information stated by the pilot and/or vehicle driver.
- **Voice recording:** some messages, as the read backs or requests from the aircraft and/or ground vehicles could be recorded to give the ATCO the possibility to retrieve the communication at a later point in time. "*Consequently, if the controller is busy transmitting / receiving a transmission at one aerodrome a pilot could anyhow transmit on another aerodrome at the same time. The controller would then listen to the recorded transmission and provide feedback to the second pilot*." (OSED 2015: 51)
- **High definition and/or infrared cameras:** the visual presentation is

considered fundamental in the transition from local to remote control, as the ATCO must always have visual contact of the area under his/her responsibility. The view of the aerodrome(s) could be provided with a camera based solution, or a synthetic, virtual image and or other systems, depending on the requirement of the aerodrome. The visibility in darkness could be provided with infrared cameras. Additional information may be overlaid on the screens, together with the data coming from other sensors and/or sources into the visual field. "The use of technologies to enhance the visual presentation may be introduced to assist working methods and situational awareness." (OSED 2015: 36)

- **Additional viewpoints:** multiple sensors on different positions on the aerodrome could provide other viewpoints, which can prevent situations in which the view could be obscured, due to three growth or new building construction, etc.
- **Binocular function:** this function could facilitate the operator(s) when s/he needs to look more closely at objects in his/her field of view. The operator(s) could also have the possibility to angle the view and zoom into objects.
- **Devices for the recording of data:** it could be possible to record visual information that can be used as data to support the process of investigations of incident and accidents.
- **Information sharing technologies:** the exchange of information has been considered an important factor to allow to the ATCO to obtain the local knowledge about the remote airport status, as the ATCO is not physical present. In fact, in future operations with the condition of being placed in a remote location, the local knowledge could be compensated by dedicating a specific part of the training to the airport characteristics, by regular meetings with the airport personnel and by visits to the remote airport. The dislocation of personnel and, thus, should be reinforced with the communication devices and potential changes in the digital information would be communicated to the

actors involved through devices able to make this exchange easier and more collaborative.

- **Aerodrome sound reproduction:** the use of tools able to reproduce the aerodrome's background sound is suggested in the new concept description, as it could further improve the operators' situation awareness. The implementation of the sound would depend also on the size of the airport as the biggest one usually have sound insulated tower building, meanwhile in the smallest ones the operators may still rely on the sound as additional support to the execution of their tasks. A benefit that the use of sound could add to the management of the traffic in the remote tower is the possibility to switch on or off the volume or to control it, in line with the operators' necessities.
- **Air and Ground Situation Displays:** the air situation display is actually in traditional operations (see 2.3) and in the new operational concept; they might be introduced in the Controller Working Position, based on the local requirements and needs.

Independently of which technologies will be implemented, what is considered fundamental for the new concept is that "*The technical solution should be flexible. This particularly applies to the application of the Multiple Remote Tower concept*." (OSED 2015: 82)

Chapter 4

Exploratory concepts of innovative solutions for remote control

4.1 Introduction

Automation is considered a key concept in the aviation domain because it represents the possibility to improve safety and to support ATM operators during the performance of their operational tasks. In the case of the Remote Tower Operations, where new operational paradigms are being introduced, there is a high potentiality for the exploration of automation and of the interaction with the new Controller Working Position (CWP). In this regard, this chapter describes the process that has been carried out to explore concepts of multimodal interactions for future scenarios of Remote Tower Operations. In particular, the objective of the process was to analyse existing multimodal interactions involving tools and technologies coming from multiple and different domains and then to generate proposals on how to design potential multimodal interaction features in the Remote Tower environment able to trigger a multimodal interaction among the operators and the working environment. The idea behind the exploration of the concepts arose from the theoretical framework of the embodied cognition and of the multisensory integration principles. Later on, it has been fed by the results of the sub-activities carried out during all the three design phases.

The concept of Remote Tower is very dynamic and flexible, hence it is expected that elements of the concept could be applied in a variety of ways in a wide range of operating environments. Meanwhile, these solutions must not have a negative impact on the human performance, especially during demanding situations in terms of workload and situation awareness, as well as on the safety of the operations.

4.2 Objectives

As stated at the beginning of this thesis, the research questions of the PhD study are related to the research questions of the MOTO project, reported in 1.
In 1 it has been explained the relation between the PhD research questions and the activities carried out during the year of work both on the European projects and on the thesis, which contributed to the acquisition and the improvement of the competences necessary to structure the PhD workflow. As mentioned in 1.2.1, the questions that the design process tried to answer are the following:

2 Is there any impact of multisensory integration on ATCOs' performance in control tower operations?
    2.1 If yes, what kind of impact is there, specifically with regard to situation awareness and workload?
    2.2 What kind of suggestions for the design of multimodal solutions can be provided to support ATCOs' performance in Remote Tower Operations?

The PhD research questions have been used as a starting point for the activity on the concept design, detailed in the following sections, in particular to:

- Explore the field of multimodal interaction and related technologies in multiple domains (e.g. art, industry, medicine, psychology, technology and etc.);
- Develop visual scenarios to explain future application of the proposed multimodal interaction solutions in operational RTOs tasks.

Contrary to traditional design processes, where the problem setting stage comes directly from the stakeholders (in the form of a design brief), the design approach adopted in this research aimed to identify the core design questions from two main sources:

- Analysis of the SESAR documents, especially concerning the characteristics of the future RTOs scenarios, the new roles being introduced, or the modifications to the existing ones;

- Cross-fertilisation with other domains.

The combination of these two aspects led to the study of multimodal concepts for monitoring, predicting, communicating and intervening on the Tower Air Traffic Control system, always taking in mind that the multisensory interactions should offer support in managing the high complexity of the ATM domain as a whole network. Considering that, the first aspects that have been identified as starting points for the design process are:

- The definition and understanding of the emergent roles;
- The definition of their key responsibilities and tasks, in relation to the overall management of the ATM system in RTOs;
- The interactions among the different actors;
- The quality and complexity of the data to be managed.

All these have been included in the different specific scenarios of remote control, where new roles (and a new ATM operational setting) would require that all the working methods, the procedures and tools, the way information is visualised and the workspaces could be adapted based on new needs and requirements.

In order to design efficient and feasible concepts, it is necessary to consider all this complexity and brought it into a network where actors, tools and procedures should coherently work together. In addition, both the trends obtained with the experimental exercises and the ATCOs' feedback, involved during the focus group and the Wizard of Oz session, have been considered as references for the different sensory modalities combination analysis when designing new kinds of interaction and system functionalities.

The end result of the concepts design phase was a set of multimodal interactions proposals in the context of use, namely scenarios of Multiple Remote Tower Operations, where one Tower ATCO manages the traffic of three airports. The

context was represented in the form of scenarios, including not only the description of the solutions in place but also the physical dimension, the roles and activity of the actors, the contents that are created, modified and communicated within the system, the other users involved, the enabling tools, interfaces and the related interaction modalities, together with the functionality of the system itself.
The scenario is usually represented in form of storyboards, i.e. a linear sequence of images showing the main characteristics of a system through the representation of their use by potential users. Storyboards may have different forms; they could be a sequence of drawings, pictures or videos. The benefit of the development of concept scenarios is that they allow the users to envisage the potential of innovative solutions and, meanwhile, it is an easy-to-use, intuitive and efficient modality to gather feedback for the improvement of the whole concepts.

4.1 Design process

With regard to the approach used for the purpose of this activity, it has been adopted and adapted the co-evolutionary design methodology,

> "*an inter-disciplinary approach to design in ATM that encourages intersections between art, design and technology borrowing from each discipline practices, methods and experience for the definition of innovative concepts*" (Marti and Moderini, 2002: 1)

During the initial steps of the design, the main activities on concept design, user research, technology and strategy insights worked autonomously but they also ran in parallel, with the aim to explore the boundaries of the design space from different perspectives. The parallel execution of the above-mentioned strands triggered an exchanging process of information and of mutual influence among the activities without any constrain.
The concepts design process consisted of three main phases:

1. **Problem setting**;

2. **Concept Generation**;
3. **Concept Development**.

The **Problem Setting** phase was structured with a preparatory step during which an experimental exercise has been performed; then an initial benchmarking of multimodal technologies has been built; later on a workshop was organised with four Human Factors experts in aviation with a background in concept design.

The workshop objective was to discuss about existing and potential multimodal interactions taking place in various domains, from the videogames to the automotive fields, with the support of inspirations coming from the literature and web research on multimodal interactions and techniques.

The results of this step consisted in the collection of initial ideas on potential scenarios and draft concepts to be implemented during the controller performance in managing remote operations.

The **Concept Generation** process was dedicated to investigate and develop activities around different interaction paradigms and preliminary suggestions, combined with refinement phases during which the conceptual framework was iteratively adapted to the results of each activity. The analysis and exploration of the technical requirements and the related implications influenced the process, during which the first assumptions were also revised. Before the final storyboard version was produced, additional ATM and human factors experts' feedback has been gathered in order to assess the feasibility of the new interaction modalities identified between the operator and the working environment.

The final phase, **Concept Development**, aimed to finalise the multimodal interaction concepts proposal in the scenarios of use on the basis of the results achieved during the previous phases. At the end of this step, a storyboard has been produced in order to envision how the proposed solutions could work in future scenarios of Remote Tower control.

Three workshops have been organised to carry out the activities of the above-mentioned phases in a collaborative and multidisciplinary environment, where the participants exchanged views about which multimodal interactions options to explore and which not.

In the following chapters, detailed information is provided for each step of the design approach, together with the activities performed inside each phase.

4.1.1 Step 1 – Problem setting

The focus of the first phase was to carry out a set of parallel activities with the aim to collect the preliminary ideas on design requirements, both from the aviation domain and from totally different ones. During the problem setting phase, the aviation field has been analysed from a design perspective, with a special attention on the target users, their roles and responsibility, the core activities within the RTOs and the technological requirements and suggestions coming from the literature review. Meanwhile, an inspirational benchmark with evocative ideas and technologies from other fields has been prepared. This information has been used to define the boundaries of the design space, and in particular to:

- set a design centric approach and perspective;
- identify the key aspects that influence user's interactions with activities, operations and services during Remote Tower Operations;
- Refine design objectives based on a preliminary analysis of the context: users' needs, their roles and responsibilities in future scenarios of RTOs, the phases of activities in RTOs and the technical enablers.

In synthesis, the main objectives of this phase are the following:

- to set-up and frame the problem considering different perspectives: user, design and technology;
- to identify and elaborate key questions and opportunities in relation to Tower ATCOs operations;

- to explore different multimodal interactions and design possibilities.

The main activities performed within the problem setting are:

1. **Design questions and definitions:**
    a. **Target users:** understand the (new) ATM domain, identify the main activities, roles and responsibilities and needs of the target users, both in terms of features and tools; analyse the collaboration between the different actors in performing ATM related tasks;
    b. **Activity model**: analysis of the working environment, including the identification of the activity phases;
    c. **Design space**: analysis of the spatial organization of the new working context;
    d. **Scenarios:** definition of future scenarios and performances, together with the identification of human roles in reference SESAR scenarios, considering also the current tasks and the emergent roles.
2. **Experimental exercise:** conduction of an experimental test to gather trends on the impact of the multisensory integration on Tower Controllers' performance.
3. **Inspirational benchmark:** fulfilment of an inspirational benchmark with innovative multimodal technologies applications and interactions in different fields, ranging from medicine to art, from automotive to biology.
4. **Preliminary multimodal interactions definition:** organisation and execution of a workshop with Human Factors experts in aviation, in order to define a set of parameters to be used to collect information on multimodal interactions.

In the following sections relevant aspects used to frame the design of multimodal interactions have been analysed, in order to proactively support the different phases of the Tower Air Traffic Controller's activity.

With regard to the definition of the design questions, the following issues have been examined and taken into consideration for the problem setting:

- Target users;
- Activity model;
- Design space;
- Scenarios of RTOs.

4.1.1.1 Design questions definitions

With regard to the definition of the design questions, the following issues have been examined and taken into consideration for the problem setting:

- Target users;
- Activity model;
- Design space;
- Scenarios of RTOs.

Target users

The identification of the target users aimed to understand the Remote Tower Operations domain, to identify the main activities, roles and responsibilities of actors involved, to analyse their collaboration in performing ATM task-related, with a focus also on features and tools influencing the interaction.

As reported in chapter 2.4.4, the target users mainly and directly involved in the future concept of single and multiple remote tower operations are:

- Air Traffic Controller(s) and/or Air Flight Information Service(s);
- Supervisor.

The target users may change accordingly to the kind of service the controlled aerodrome requires and based on the remote tower module configuration (Figure 7) that can foresee the introduction of more than one ATCO and of a supervisor position. The additional roles could be necessary if during a specific operation further support is needed to guarantee an acceptable level of safety and efficiency.

The target user that have been considered for the PhD work is 1 ATCO managing multiple airports in parallel. The choice was motivated by the fact that the research tendencies are currently going towards the implementation of a Remote Tower working position featuring the single operator position.

Activity model

The analysis of the activity had the purpose of exploring the context of work, including the identification of macro-areas of activity and the interdependencies between the different tasks.

In order to define the set of activities performed by the target users, a review of the following documents have been done:

- The task analysis of the Tower Control Operations performed in the RETINA project;
- Task analysis literature review (Appendix C);
- OSED D35.

This activity has been enriched by a cycle of observations to the Tower ATCOs' tasks at "G.B Pastine" airport of Ciampino (Rome).

The review of the above-mentioned documents and the observations at Rome airport gave the opportunity to order the ATM processes and tasks complexity. The activity model mostly considers the actors and their needs, without involving any technological consideration. The reason behind this choice is that if focusing on technologies, there could be the risk of rapid obsolescence and of anticipating the technological innovation process.

The activity model is based on the following main phases, which contributed to the boundaries definition of the design intervention areas and of the design choices.

1. **Receiving and Organize Flight Plan System (FPS):**

    1.1. Receive Strip;

    1.2. Check Strips;

    1.3. Place Strip in the Strip Bay;

1.4. Reorganize strips.

2. **Check (Carrying out Airport/Runway checks):**
    2.1. Check weather (wind/rain/visibility);
    2.2. Check traffic (out of the window view/ surface radar);
    2.3. Check for RWY (wake vortex, objects, inspection in progress);
3. **Monitor:**
    3.1. Monitor taxi route;
    3.2. Monitor flight path;
4. **Communicate (aircraft and vehicles on the surface):**
    4.1. Communicate with aircraft;
    4.2. Communicate ground vehicle;
    4.3. Coordinate with other sectors or (transfer aircraft);
    4.4. Transmit clearance to aircraft (Start-Up/Pushback/Taxi).

In addition to the four areas identified, the following tasks have been extrapolated from the content of the OSED document as integrative tasks related to the Remote Tower Operations:

- Air Traffic System has to be provided as in traditional local tower control operations;
- Collaborative planning and/or traffic coordination could improve ATCO possibility to provide ATS service to multiple aerodromes in parallel and to reduce the traffic density;
- Traffic sequencing has to be handled one at a time;
- Increase the number of ATCOs and/or outsource the tasks could positively impact on the operations if the traffic density increases exponentially.

<u>Design space</u>

In order to define the most challenging and appropriate design space as setting for the scenarios, four main sources of input have been considered:

- the knowledge of the Human Factors experts on the ATM domain involved in the two phases of concepts design (Problem Setting and Concept Generation);
- references to the future Controller Working Position set-up reported in the OSED document (see 2.4.3);
- Report of the interviews and workshops of the first activity described in 4.2.1.1.
- Experimental trends with regard to the different sensory modalities combination in the control tower operations 4.4.2.

Concerning the working space design, the analysis of the Human Factors experts' inputs, collected during the workshop held in this phase, the information provided in the OSED and the experimental exercise trends led to the definition of the following suggestions for the interaction design space.

Table 3 - Inputs for the interaction design space

Space configuration
Single Remote Tower control: 1 ATCO managing 1 aerodrome
Multiple Remote Tower control: 1 ATCO managing more than 1 airport in parallel (1:2, 1:3, 1:n)
The **Remote Tower Module** could be located anywhere, but to improve the cost-effectiveness, it may be in a Remote Tower Centre (RTC)
Aerodromes located in the **same geographic area or in the same controlled area** can be combined
Combination of airports in an RTM can be based on aerodrome **size**, their **traffic peaks** and their **runway layout**: • Size: o Big aerodromes are clustered in small groups in an RTM; o Small airports are often in the same large clusters; o Large airports and much smaller ones are grouped together, in order to have a more balanced traffic; • Traffic peaks: airports with overlapping traffic peaks are not grouped; • Runway layout: aerodromes with different runway numbers and/or direction are in the same set.

Systems functionalities
Flight Progress Strips: integration of the flight strips of more than one aerodrome into one device, namely the Flight Data Processing Systems, where the strips have a different colour coding, depending on the aerodrome they belong to.
Indication of the transmission source: a function able to highlight where a radio transmission is coming from.
Warnings: different types of alarms detecting and informing on different kinds of conflicts.
Voice recognition: • the system recognises ATCO's instructions; • the system recognises information stated by the pilot or vehicle drivers
Additional viewpoints: function providing other viewpoints, when the view could be obscured (e.g. three growth or new building construction).
Aerodrome sound reproduction: possibility to reproduce the aerodrome's background sound and to control the volume (e.g. switch on or off it). The implementation of this function may vary depending on the size of the airport and if they are sound insulated or not.
Air and Ground Situation Displays: they might be introduced in the Controller Working Position, based on the local requirements and needs.
Recording of data: function that allows the recording of visual information to be potentially used during investigations of incident and accidents.
Interaction potentialities
Possibility for the operators to **switch the control from one aerodrome to another** in any moment s/he has to provide ATS to those airports under his/her responsibility.
Chance to **share or duplicate some features** required for the provision of ATS to more than one airport. This function must allow differentiating which aerodrome the display and/or other systems relate to.
Continuous and simultaneous displaying of images of each **aerodrome** under control.
Possibility to **hide the screen** when it is not needed and to easily come back to the hidden visualisation when his operation is required.
Continuous view of the aircraft and of other vehicles to be maintained.
Chance to **enlarge the primary airport** controlled and to display the secondary ones on an equal in size presentation or on smaller screens.

Possibility to provide the **ATS service without a visual presentation** for airport where for a long period of time (e.g. 1-2 hours or more) no movements are scheduled.
Multimodal Interaction modalities
The **integration of visual and haptic inputs, as well as the visual and vibrotactile** ones improves the ATCOs' performance in terms of situation awareness and workload.
The integration of **visual, haptic and vibrotactile** inputs does not increase ATCOs' performance in scenarios with high level of complexity.

The goal of this categorisation was to take into consideration these aspects into the generation of multimodal interactions proposals, offering support to the target users' performance. This classification is one of the results of the problem setting phase and as such, it oriented the design objectives and process, the opportunities space that the design needs to address, as well as the ATCO's Human Performance aspects which could be positively impacted by the multimodal integration.

Scenarios of Remote Tower Operations

From the review of the OSED, it was clear that the main interaction between the ATCO and the environment passes through the visual channel. In fact, in the Use Cases (OSED D35: 85-108), the ATCO performs his/her tasks thanks to the support of tools enhancing the visual observation, for example through overlaid information on the screens. In the OSED D35 it is also considered the introduction of devices stimulating other sensory channels but they are mainly dealing with the auditory channel, while for other kind of interaction (e.g. vibrotactile) the example are not detailed. This observation offers the possibility to explore the multimodal interaction, especially with the introduction of solutions based on the multimodal integration theories.

Another fundamental input coming from the review of the OSED is the classification of the different configurations of the ATCO working positions. In regard to the Single Remote Tower Control, it is considered only one position (i.e. 1 ATCO managing 1 aerodrome), while for the Multiple Remote Tower there is more than one configuration. These configurations have been analysed in order to consider them in the definition of the scenarios; the final Multiple configuration was the one finally chosen. However, when taking into account the first draft of the multisensory interactions explored in this phase, it was considered the possibility to use them also in Single RTOs contexts, depending on the specific situation to analyse and on the users' needs to satisfy.

In addition to the above-mentioned use cases, the inputs provided by the ATCOs during the interviews (4.2.1.1) have been considered in order to have more extensive examples of potential events to be implemented in the scenarios. With regard to this point, the most interesting and inspiring feedback from the interviews was the reference to the cases in which an inspection occurs on the runway. According to what the ATCOs reported, in case of inspection on the runway, the risk of a loss of attention when the process is in progress could be very high, as well as the probability to get used to the auditory stimulus notifying the event (e.g. the warning alarm that lasts about 20 seconds). These risks are highest especially at small airports where movements are not foreseen for a long period of time (around 20 minutes). This event is worth looking into, as it could have a negative impact on the management of the flights, in terms of situation awareness and workload of the operators. When an inspection occurs, the controller finds strategies to remember the event and to maintain an acceptable level of attention, as for instance moving objects from one position to another (e.g. paper strips and microphone) or to report the aircraft information on the strips.

The inspection case has been later explored as an example of multimodal interaction scenario to study during the second workshop.

The above-mentioned experimental trends have been considered during the concept generation phase, when deciding which combination of stimuli could represent the desirable one for the design of future multimodal interaction between the Tower Air Traffic Controllers, the Controller Working Position and the other roles involved in the Remote Tower Operations.

In fact, the most interesting trends for the design refer to the combination of the Visual and Auditory (VA) modalities and of the Visual and the Vibrotactile (VV) one, which appear to improve the ATCOs' situation awareness in the Easy and Hard scenarios and the level of workload in the Hard ones. In addition, when the Visual, Auditory and Vibrotactile (VAV) stimuli are all mixed, the ATCO experiences a performance decrease in high level of complexity situations (e.g. high traffic volume). This last result could be due to the fact that providing all the three sensorial inputs, the ATCO can be confused or distracted by them, losing the attention on the environmental elements and on those tasks requiring the operator to act and react in a short period of time.

4.1.1.2 Experimental exercise

4.1.1.2.1 Preparatory activities

As stated in chapter 1, starting from the MOTO approach and its two research questions, the PhD study posed additional questions and objectives, which are related to MOTO in a dynamic exchange of knowledge and results.

To this end, this thesis correlates the experimental exercise activities performed in the framework of the MOTO project, with the design process mainly carried out inside the PhD: the exploration of multimodal interactions concepts, which can support the TWR ATCO in future Remote Tower Operations.

The scenarios developed for the experimental exercise were only one of the inputs used for the development of the scenarios included in the Concept Generation phase. The events included in the experimental exercise scenarios were created considering the technical limitations of the equipment used to reproduce the scenarios during the experimental exercise. As for the concept generation step there were not specific technical constraints to be considered for their eventual implementation, it was possible to include further operational and procedural aspects in the set of innovative solutions scenarios for Remote Tower Operations detailed in chapter 3.1 . In addition, the results of the experimental exercise have been taking into consideration also as one of the reference for the selection of the different sensory modalities to combine in the multimodal interactions scenarios. On the other side, the concepts developed in this thesis could be one starting point for the definition of the interactions to implement in the VR experimental exercise foreseen in one of the MOTO project WP 3 reported in chapter 1.1.1. Moreover, depending on the project technical requirements and needs they could be slightly changed in order to adapt them to the experimental context.

In regard to the experimental exercise, at the beginning of the MOTO project a set of operational needs has been identified, namely a group of operational scenarios, which are the descriptions of how the tower control is performed in everyday operations. The operational needs (scenarios) aimed to test if the multisensory integration improves the human performance in the current day-to-day operations of the tower controllers.

Here below the activities performed to develop the exercise are summarized and then they are detailed in the following chapters:

- Identification of preliminary operational scenarios:
  - Interviews;
  - Workshop.
- Literature review on the following HF concepts: workload, situation awareness and task analysis techniques;
- Development of the experimental protocol;
- Execution of the experimental exercise;
- Data analysis and discussion.

After the identification of the scenarios, the experimental exercise has been prepared. The preparation of the simulation included the development of an experimental plan, which comprehends the experimental protocol and the measurement techniques used to evaluate the Air Traffic Controllers' performance. During this step, the more appropriate measurement techniques have been selected in order to have an extensive set of assessment methods to be used for the collection of data on situation awareness, workload and performance. In particular for the measurements of the situation awareness a review of the methods used in aviation have been performed and the SASHA questionnaire (EUROCONTROL 2003) have been selected and adapted for the purpose of the validation. The same process has been followed for the workload that ended with the selection of the NASA-TLX: a standardized multidimensional assessment technique that rates the level of workload perceived by a subject; this technique has not been modified as it is a consolidated measure for the collection of data on the workload. The above-mentioned questionnaires have been inserted among the set of data collection techniques used during the exercise, in order to have a more extensive pool of results to be analysed to validate or discredit the research hypotheses.

Identification of operational scenarios

The purpose of this activity was to identify scenarios of current local tower operations to reproduce a realistic multisensory tower control environment in a laboratory setting. The scenarios describe multiple situations of the context under analysis, in terms of physical dimension, the roles and activity of the actors, the contents that are created, modified and communicated within the system, the other users involved, the tools, the interface and the related interaction modalities, together with the functionalities of the system itself.

Two sub-activities contributed to the choice of the scenarios, namely:

1) Interviews;
2) Workshops.

The aim of the activities was to identify and select scenarios of tower operations where multimodal perception plays a role, and under low and high workload conditions. The first step was to do a gap analysis on the current Remote Tower Operations, together with an analysis of the scenarios that have been already developed and validated in the framework of other projects and activities on RTOs.
After the interviews, a first set of scenarios have been developed and, then, it has been refined thanks to the expertise of Air traffic Control invited to participate in two workshops.

Interviews

An interview has been developed and carried out to three Italian Air Traffic Controllers, whose feedback has been used to detail and improve the description of the scenarios, especially with regard to the operational aspects (e.g. tasks sequencing, procedures to apply in case of emergency, systems and tools used in the control position, etc.).
The interviews were structured in a brief introduction on the MOTO project, to give a clear understanding of its objectives, and then it was followed by seven questions on the topics listed here below:

- Interviewee's experience with Remote Tower Control;
- Differences and similarities between current tower and Remote Tower Operations;
- Multimodal interaction (involving sight, hearing, tactile perception, etc.) between ATCO and working environment during current control operations;
- Information received by and provided to ATCOs during the (multimodal) interaction;
- Phases of flight impacted by the multimodal interaction.

The interviews were executed together with a Human Factors expert to the following subjects and each session had duration of around an hour:

- 1 Air Traffic Controller from Milan airport “Milano-Malpensa”;
- 1 Air Traffic Controller from Bologna airport “Guglielmo Marconi”;
- 1 Air Traffic Controller from Venice airport “Marco-Polo di Tessera”.

In the following paragraphs the results of the interviews are reported in relation to each topic addressed during the discussion with the ATCOs.

In the final paragraph, **Outline of the interview**, a summary of the main points of the ATCOs answers is provided.

1. **Interviewee’s experience with Remote Tower Control**

The first question aimed at understanding if the ATCO had ever had any experience with Remote Tower Operations and which level of knowledge he had about it.

The results was that the three air traffic controllers have never had a direct experience with remote tower operations, nevertheless they know the state of the art of the research about RTOs at a high level, that means some of the new technologies which are been developing (e.g. SAAB prototype of remote tower).

2. **Differences and similarities between current tower and RTO operations**

In regard to this topic, as the interviewees did not have any direct experience with RTOs, they could only hypothesise how the controller’s work can change, and on which aspects there could be an impact in the transition from the current operations to the remote ones.

The main change identified is in the substitution of the view of the real world outside the window with high definition screens, which will reproduce the images of the controlled airport. This demonstrates that it is commonly known that the research in the RTOs is mainly exploring and investing visual technologies.

None of them have mentioned technologies or other solutions that will involve other senses during the operations, confirming some of the assumption of MOTO background.

3. Multimodal interaction between ATCO and working environment during current control operations

The interviewees did not provide any specific feedback on multiple modalities of interactions, in spite of that it was highlighted the importance of the integration of different kinds of stimuli, as for instance the auditory, the visual and the perceptual ones with the situation awareness.

During the three interviews, it came out that the most stimulated sensory channel is the visual one, together with the auditory channel, which is involved during the communications via radio with the pilots and with the ground personnel.

4. Information received by and provided to ATCOs during the (multimodal) interaction

One of the body interactions with the environment, which has been mentioned by the ATCOs, is the perception of the tower vibrations due to strong winds, which in some situations allows the controller to anticipate his tasks for few seconds.

The recognition of the relation between the vibrations and the wind comes with the experience in working as tower controller. In the interviewee's view, if a controller works in a tower X, once moved in a tower Y, s/he will not be able to immediately recognise the vibrations and what they depend on. Even if the controller firstly entrusts the instruments rather than body perceptions, it has been recognised the importance of the physical perception of the vibrations.

The controllers highlighted also that physical perception gives anticipation, while the information provided by the technologies and tools is considered as a certainty and a confirmation.

Moreover, the wind direction and how it can change must be continuously monitored, above all if the airport controlled from a remote tower has a low traffic density. As said by the controllers, sometimes it can happen that the wind changes between one flight and another; these changes must be considered because they can influence the controller's management of the flights.

5. Phases of flight impacted by the multimodal interaction

With regard to this issue, one of the examples provided by one of the interviewees is related to the control phase of an aircraft landing with a higher speed level than the standard one. In that situation, the controller receives the information on the situation that impacts in different ways on multiple sensory channels: on the visual one through the support of the ground radar (SMR – Surface movement radar) and through the aircraft and the runway illumination; on the auditory channel through the radio communication (e.g. correct read-back of the pilot and the controller) and via vibrations produced by the tower building (vibrations may differ depending on the kind an position of the tower). The perception of the engine sound can change based on the position of the controller and on the direction of the aircraft.

In addition a description of the multiple steps occurring during a landing has been provided by one of the ATCO during the interview and it is reported in the following points:

- Pilot report of the aircraft position;
- Weather data acquisition;
- Visual control (radar or report of the position);
- Check of the landing procedures;
- Monitoring continuously the runway (few minutes before the landing);
- Check of the wind variations;
- Landing: new acquisition of information on the runway status.

6. Additional relevant information

In addition to the information provided in the following sections, the three ATCOs described also another situation, occurring frequently during the controllers' job, which according to them is critical and has an impact on the management of the flights, in terms of situation awareness and workload of the operators.

The situation in question refers to the inspections/operations on the runway. In those cases, the controller must find strategies to maintain her/his situation awareness at high levels, as for instance to move objects from one position to another (e.g. the microphone) and/or to report the aircraft information on the strips.

Figure 11 - Cardboards on the radio and on a monitor indicating the runway check

Figure 12 - A special paper strip placed on the strip bay

There are around 15 inspections per day and they can be:

- Runway inspection;
- Monitoring of birds presence with:
    - Sound signals;

        - Falconers;
        - Kites.
    - Maintenance of the runway lights.

The inspections and operations are communicated to the controller through the surface movement radar, radio channels and through the use of panels with bright signals. This example has been repeated quite often by the interviewees, as the risk to get used to the stimulus (e.g. the sound signals giving a warning for around 20 seconds) and the likelihood of a loss of attention can be very high. In current small tower control, dozens of minutes can pass without any aircraft movements.

In order to help the controller in avoiding the decrease of attention, the warnings regarding the presence of inspection on the runway must vary in time. In case of bad visibility, the controller entrust the radar instruments, the pilot's report and the radio communication in order to check if the runway is free of inspection or not. In those situations there could be an increase of the workload level and a decrease of situation awareness, as the effort to keep the attention on the tasks is higher than in other cases, for instance when there is good visibility.

The information on the runway operations has been considered relevant for the definition of the scenarios because it was mentioned by all the controllers and, moreover, the difference between the level of situational awareness and workload during those operations, between day and night, gave input on the choice of day/night shift to use in the scenarios, accordingly with the decision to create nominal or non-nominal scenarios.

7. Outline of the interview

From those results, the following aspects have been considered for the selection of the scenarios and included in their description prepared after the interviews and before the workshop with the ATCOs.

- **Weather conditions**:
    - Good visibility;

- Bad visibility:
  - wind (Bologna, Venice and Milan airports);
  - fog (Bologna airport);
  - snow (Milan airport).
- Display for weather data.

- **Size and position of the tower and of the airport**: these two characteristics of the tower building can affect the possibility to perceive the vibrations coming from the winds or the sound engine. The weather conditions, the typology and complexity of the airport have been reported as variables influencing the work of the controller. In bad visibility situations, for instance, the controller entrust the tools, in particular the radar, the parking and the runway lights.
- **Operations/Inspections on the runway** due to the presence of:
  - animals;
  - obstacles;
  - maintenance technicians and ground personnel;
  - wet areas on the runway.

For those situations, the interactions between the ATCOs and the technologies were also taken into consideration, in particular:

- *Technologies:*
  - Ground and aerodrome radar: to detect obstacles on the runway and for the aircraft movement;
  - Radio channels: for the communication with the pilot, the ground and maintenance personnel of the inspections;
  - Bright panels warning on runway operations.
- *Interaction/ Strategies for high level of situational awareness:*
  - Use of strips;
  - Objects movements (e.g. microphone)

- **Dayshift:** easy to see the aircraft landing and obstacles on the runway;
- **Nightshift:** higher attention in following the aircraft, because there are a lot of lights (those of the aircraft and of the runway).
- **Traffic density**: the remote control of an airport with low traffic density could produce an enlargement of the waiting moments between one flight and another.

From the analysis of the interviews results, a set of six scenarios has been developed and a specific template has been created with the aim to present and describe them in an easy-to-understand way during a workshop organised to discuss and consolidate the scenarios with experts of Air Traffic Control. These scenarios (reported in Appendix B) represented a first step of an incremental approach aiming to study the potential impact of multimodal stimuli on ATCO's performance in a remote tower platform.

The situations described in the scenarios have been considered relevant for embodied cognition, as for example, in regard to the scenario of "Heavy fog", a lack of visual stimuli could be balanced by other sensory perceptions (as the auditory ones), able to send to the ATCO supporting information to the completion of his/her tasks. The "Runway Inspection" has been selected because in the interviews it was identified as a situation that can have a negative impact on the situation awareness and, thus, the exploration of the integration of multimodal stimuli could help the ATCOs to be more aware of the context, maintaining acceptable level of the performance.

In addition, the scenarios described both nominal and non-nominal situations, in different meteorological conditions and considering multiple phases of flight, in order to have also a range of representative descriptions of the tasks the ATCOs could have to deal with in RT operations.

Workshop

The preliminary scenarios described above have been discussed during a workshop with the aim to analyse and validate them with the professional ATCOs from different Italian Control Towers.

The meeting was held in Rome at Deep Blue headquarter the 23rd September 2016, involving partners of the project and ATCOs.

Here below the list of the participants:

- 4 Human Factors experts from Deep Blue;
- 2 Neuroscience experts: 1 from Industrial Neuroscience Laboratory (IN-Lab); and 1 Social and Cognitive Neuroscience Laboratory (SCN-Lab).
- 4 Air Traffic Controllers:
  - 1 TWR ATCO from Fiumicino "Leonardo Da Vinci" airport;
  - 1 ATCO Responsible of "Roma Urbe" airport;
  - 1 TWR ATCO from "Milano-Malpensa" airport;
  - 1 TWR ATCO from Venezia "Marco-Polo di Tessera" airport.

At the beginning, the main objectives and goals of the workshop have been presented, together with the experimental approach, the expected results and the potential benefits of a multimodal interaction for the Remote Tower operators.

Later, an overview of the key concepts underlying the embodied cognition was given, providing examples from psychophysiological and experimental field.

Once concluded the introduction and the overview of the embodied cognition, the preliminary scenarios (reported in the previous section) were presented to the participants. The discussion was focused on the role of the embodied cognition and the multisensorial feedback during the selected operations and tasks. ATCOs were also asked to provide further examples of multimodal stimuli that may impact on the tower operations.

The most relevant information provided by the participants was related to the information regarding the auditory channel and to the characteristics of the tower building.

In regard to the auditory channel, the feedback provided gave some indications on the possibility that this kind of information could be a useful indicator in particular in situation of low visibility conditions, which could potentially involve technical malfunctions. In this regard, an example was reported by one of the participant. In the situation described, a Tower ATCO received a call from a landing aircraft declaring fuel emergency and the relative emergency procedures started. During the operations, the position of the fire brigades involved made the stop bars alarm go off and, thus, the ATCO relied on the engine reverse sound of the aircraft to know when it had landed, as no visual information was available, due to the low visibility conditions and to the switching off of the stop bars alarm.

This event was reported to provide an example of the support that the auditory information could provide in some situation. In the above-mentioned case, the reverse sound of the engine gave the ATCO the confirmation of the effective aircraft landing.

Other comments were made with regard to the occurrence of thunderstorms. In this case the reproduction of the rain sound and direction could help the operators to improve the understanding of the situation and to improve the level of “reality” and immersion of the controllers while operating from remote positions. In addition, it was argued that in the RTO, in case of different weather conditions between the airport where the control is performed and the remote airport, the ATCO needs to do a mental operation to put her/him in the same situation as if s/he were controlling the traffic from a local tower.

ATCOs report that in case of use of engine reverse sound during the deceleration run, this typical sound could also help to estimate the (future) position of the aircraft. For example, in case of a tight sequencing, it could be useful to know how the aircraft on the runway is acting and the reverse sound may give indication of an higher rate of deceleration (then the a/c may be faster in vacate the RWY). This may support the ATCOs working method to better optimize the arrival sequencing.

Moreover, it was argued that the auditory stimuli can complete the visual information, as for example in case of an engine failure or when multiple vehicles are controlled, as in the case of the scenario on IFR and VFR flights. In this regard, according to the participants it is difficult to understand the position of a VFR aircraft, like a helicopter, from the direction of the vehicle because the wind changes the sound. Then, it was added that once the aircraft is visible and at the same time the controller hears the sound of the vehicle that is the moment in which it is possible to match the auditory and the sight perceptions.

Usually, when the controller perceives the sound, s/he has already made the decisions. The sensory information is more a confirmation that comes when the controller has already started the task. Despite that, it was also highlighted that with low traffic conditions the sound stimulus can be useful to attract the attention of the controller.

With regard to the auditory perceptions, the wind direction is considered very relevant information during the landing phase. Beside the data reported by the anemometer the ATCOs use also some points of reference to understand the wind direction. The points of reference depend on the kind of airport; they can be different from one airport to another. For example, in Fiumicino the controllers look at the position of the oil tankers next to the airport, while in Venice ATCOs simply use the wind sock. In Remote Tower Operations the possibility to visualize these points of reference could be useful to the ATCO in order to have a feedback on wind direction, integrated with the auditory information, according to the controller's experience in a soundproofed tower building or not.

Participants reported that this kind of auditory stimulus could be a good support in a small airport to be controlled from a remote tower, as it can give additional information on changes in the environment.

Another relevant item discussed during the workshop was the characteristics of the tower building.

It was highlighted the importance of differentiating between insulated towers and not insulated ones. In those towers that are not insulated, ATCOs are usually “sensitive” to the external noise, including the aircraft engine noise: some of them report to use the auditory information (e.g. the engine reverse sound) as reference in specific tasks or as further support for the identification of aircraft. In an insulated tower, on the contrary, ATCOs cannot rely on the external sounds of aircraft and they typically work in a “silent” environment.

This difference may have interesting implications in terms of RTO personnel selection and training. With multimodal RTOs, controllers that usually work in a soundproofed tower may perceive the reproduction of external sounds, such as the aircraft engine noise, as disturbing. While ATCOs used to working in a “noisy” environment, may feel that “something is going wrong” if external noises are not reproduced in the remote tower setting.

Following the workshop, the preliminary scenarios have been modified to include participants' feedback and comments.

The final session of the workshop was dedicated to a brainstorming during which it was asked to the participants to suggest innovative solutions, which could support or improve operator performance in a remote tower scenario.

During this session, it was highlighted the importance of understanding which sounds from the outside world and the inside environment can play a relevant role for the embodiment and, thus, can be selected to be integrated in scenarios of RTO.

The participants provided some examples of innovative solutions that are summarized here below:

- **Satellite signal or warning alarm:** It could be used to inform the ATCO about the vehicle position on the runway during maintenance work. The participants explained that during the inspections they put in place personal strategies to maintain a high level of situation awareness and, thus, the introduction of a satellite signal or a warning alarm could be explored in a remote tower scenario, together with other sensory stimuli, in order to help the ATCO to have a better understanding of the operations on the runway.

- **Interactive label:** Also this technology was suggested for the scenario of runway inspection. The proposal was that the interactive label could be used to give information on the state of the runway inspection with a coloured output integrated with a warning alarm.
- **Electronic strips:** For this proposal there were not specific indications on innovative ways of including the strips in RTO scenarios. It was only suggested as a solution to be further developed as a support to the ATCO during situations of inspection/operation on the runway.

The input on the innovative solutions collected during the brainstorming has been analysed for the concepts design activity, during which it has been explored if and how these solutions could be implemented in a scenario of embodied remote towers. In particular it has been analysed the technological possibilities to enhance human performance.

4.1.1.2.1.1 Review on Human Factors concepts

The data collected during the workshop gave also inputs to the identification of relevant human performance concepts and aspects to be measured during the experimental exercise. The aspects that have been chosen to be measured in the experimental exercise were the Situation Awareness (SA) and the workload.

With regard to SA, during the workshop the ATCOs highlighted that the sound of the aircraft engines (auditory information) gives additional information on the aircraft positions and on the predicting future movement of the vehicle, as for example when the aircraft is preparing the engines for the take-off. Moreover, the participants argued that in the moment in which the aircraft starts the engines, even without visual contact, the ATCO knows that he has to be prepared to start a set of tasks in few minutes. The perception of the sound was considered as a useful stimulus for the controller to be ready for the situation, especially in RTO where the controller is not located in the same place of the aircraft waiting for the take-off. It is fundamental to consider also that nowadays not all the tower buildings are soundproofed. The inclusion of auditory information in a remote tower may require a prior analysis of the controller background and previous experience to ascertain if s/he already uses auditory information during the tasks or not, in order not to give an information which could negatively impact on the SA.

In regard to the workload, it is worth mentioning a comment provided by an ATCO during the workshop that focused on the importance of integrating the auditory information in a remote tower control scenario. In particular, the ATCO explained that during his participation on a Remote Tower Flight Trials the controller had to manage the take-off phase of an aircraft but the platform did not have the auditory information integrated. The ATCO explained that he missed the engine sound feedback as confirmation of the successful take-off, provided in terms of auditory feedback. To have the confirmation of the situation, the controller had to perform an additional task that consisted in communicating with the pilot. This additional task entailed that the ATCO had to spend more time in the execution of a task and this could have a negative impact in terms of quickness and accuracy of the performance, with negative consequences also on the level of workload.
The auditory information in remote tower operations can, thus, be considered a necessary confirmation feedback for the controllers in order to maintain an acceptable level of workload.

The techniques used to measure both SA and workload has been performed and a brief review for each of the two HF concept is reported here below.

Situation Awareness literature review

Over the last years, the number of human factors problems has grown and "practitioners must deal with human performance in tasks that are primarily physical or perceptual, as well as consider human behavior involving highly complex cognitive tasks with increasing frequency." (Endsley 1995a: 32). In this context, the progresses in the technological field brought to the creation and the development of several dynamic and complex systems that require the human beings to have an effective performance under multiple aspects, as for instance in regard with the decision-making ability.

One of the most controversial and explored human factors issue is the Situation Awareness concept, which has gained popularity in the majority of domains dealing with human performance in complex and changing environments, as for example in the air traffic control with the research project by Hauss & Eyferth (2003), Endsley and Smolensky (1998), in aviation in general with Kaber et al. (2002), Keller et al. (2004), as well as in the automotive domain (Zheng, McConkie and Tai 2004, in Salmon et al. 2006). It became necessary to acquire and maintain an acceptable level of SA in complex and changing environments, where in the majority of cases the individuals are required to take several decisions and to update the environmental information in a short time frame.

The SA concept is far from having a unique definition, as well as one shared measurement technique; in fact, multiple are the descriptions and the methodologies used to assess the situation awareness and there is an intense discussion on the validity and reliability of SA measurement approaches, in particular on which is the best technique for the evaluation of this HP aspect and whether they effectively measure just situation awareness excluding other kinds of constructs.

In this brief overview on SA, three predominant SA denotations among the practitioners community are mainly reported: i) Endlesy's three-level model (1995a); ii) the activity theory model by Bedny and Meister (1999) and iii) the perceptual cycle model by Smith and Hancock (1995).

Endsley (1995a) describes the situation awareness as "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley 1995a: 36). As explained by Endsley, the SA construct does not simply mean to be aware of the amount of data in the surrounding environment, but more to know the state of the world including the involved system elements, as well as to be aware of the "future system states" (Endlsey 1995a: 32) in line with the operator's scopes. This knowledge, according to Endsley, gives the basis for the decision-making process and the human performance in the environment.

Moreover, Endsley's definition considers situation awareness as a "product" constituted by three hierarchical levels: "level 1" consists in the perception of relevant elements' status and its dynamics in the surrounding environment; "level 2" is the understanding of the meaning of the "level 1" elements with regard to the scopes; and "level 3" concerns the projection of the environmental elements future actions, thanks to the comprehension of the situation and of the elements status and their changes.

In the air traffic controller's job, the operator needs to collect data on several traffic elements in order to choose, for instance, the free runways and/or to provide the minimum separation information as well as to avoid potential collisions. The air traffic controllers "must maintain up-to-date assessments of the rapidly changing locations of aircraft (in three-dimensional space) and their projected locations relative to each other, along with other pertinent aircraft parameters (destination, speed, communications, etc.)." (Endsley 1995a: 34)

According to the situation awareness as a perceptual-cycle, theorised by Smith and Hancock, the process consists in the achievement and the update of the SA knowledge that "resides through the interaction of the person with the world" (Smith & Hancock in Salmon et al. 2006). In Bedny and Meister's view, SA is the human conscious reflexive process on the surrounding situation. Considering these descriptions from a theoretical points of view, Endleys' denotation represents SA as the product of the three levels elaboration; while the perceptual-cycle model sees SA more as a product of the interaction between the individual and the environment.

Moreover, in the literature on SA, different aspects are considered to have an influence on the level of situation awareness, as for example "the working memory limitations, attention distribution, current goals, mental models, schemata, and automaticity" (Endsley 1995b: 66), as well as the person's characteristics and the system design.

In the system design and evaluation, it is paramount to develop and implement reliable and valid measurement methods, which can effectively assess that the SA level of an operator in his/her working environments is not degraded by the system design. According to Salmon et al. (2006), the "reliability" of a SA measurement technique means that its final data doesn't change under the same conditions as many times as SA is assessed; while "validity" means that the applied measurement method assesses SA and not another product and/or process.

In order to do so, Endsley (1995b) defined three criteria to take in consideration when choosing and using a measurement techniques, in Endsley's view, it is fundamental that "the metric (a) measures the construct it claims to measure and is not a reflection of other processes, (b) provides the required insight in the form of sensitivity and diagnosticity, and (e) does not substantially alter the construct in the process, which would provide biased data and altered behavior." (Ensdley 1995b: 66)

Several literature review on SA measurement approaches have been carried out along the last years, among that one by Endsley (1995b) where the author categories different techniques applied in the past divided them in i) physiological measurement techniques, as for example the electroencephalograms and the eye tracking methods; ii) subjective rating measures (e.g. observer assessment); iii) performance techniques, as the imbedded and external task performance techniques; iv) freeze probes measures (e.g. SAGAT); v) questionnaires (pre-/post-trial and online ones). In a more recent literature review, starting from Endsley's studies, Salmon et al. (2006) reviewed the above-mentioned categories and defined the following ones:

- Freeze probe recall techniques;
- Real-time probe techniques;
- Post-trial subjective rating techniques;
- Observer rating techniques;
- Process indices;
- Performance measures.

Here below a brief description of each category is reported.

Freeze probe recall techniques

This technique foresees that while a subject is performing a task, the task is randomly stopped, the system displays are overshadowed and the experimenter asks multiple questions in different phases of the exercise. The subject is required to answer considering his/her understanding of the situation at the moment of the freezing and his/her answers are, then, matched to the real state of the system; at the end of the task an overall SA value is calculated. The most famous and widespread technique is SAGAT (Situation Awareness Global Assessment), which was created to measure pilots' situation awareness and it has been developed based on Endsley's model of SA. In fact, participants are required to provide information on the three level of SA, namely i) the perception of the elements, ii) the understanding of their meaning and iii) the projection of their future state.

In addition, another freeze-probe technique can be used in ATC, it is SALSA and its questions are developed considering fifteen factors of airplane flight, as for instance the ground speed, the type of conflict, the flight level, etc. The SACRI (Situation

Awareness Control Room Inventory) is an adapted version of SAGAT, specifically used to assess SA in process control rooms.

Real-time probe techniques

In this case as for the freeze-probe technique, participants have to answer a set of questions during the execution of tasks. An experimenter or a Subject Matter Expert (SME) prepares and administers the questions but the system is not blanked. The data collected to assess SA are the content of the answer and the time of response. The advantage of this technique, with respect to the freeze-probe, is the less intrusiveness as the system is not stopped during the exercise, but it can potentially divert the subject's attention toward specific elements of the environment and, thus, it can produce biased information.

One real-time probe method is SASHA (Situation Awareness for SHAPE), which has been developed by Eurocontrol to measure ATCO's situation awareness in automated systems. The SA questionnaire developed by EUROCONTROL is called SASHA and it was the results of the analysis of existing techniques, as well as of the feedback provided by Air Traffic Control instructors at the EUROCONTROL Institute of Air Navigation Services (IANS) with the support of Human Factors experts.

The SASHA questionnaire is composed of two parts:

- SASHA_Online (SASHA_L);
- SASHA_Questionnaire (SASHA_Q).

The SASHA_L is a questionnaire to be done by a Subject Matter Expert during the runs and it consists of questions on elements of the scenarios (more quantitative measures) to which the subject has to give the right answer.

Instead of the SASHA_L, for the purpose of the experimental exercise, it has been prepared an ad hoc questionnaire for the SME, who is described in the next section.

SASHA_Q is a post-run questionnaire that the subject has to fill in to do a self-assessment of his/her situation awareness.

The SASHA Questionnaire (SASHA_Q) design considered well-recognized Human Factors principles (e.g. open/closed questions, vocabulary and clarity, rating scales, and etc.). It is a self-rating questionnaire to be completed by the controllers involved in the simulation (i.e. it is not designed for other observers).

This part includes both questions of a generic nature (i.e. not dependent or not related to specific aspects of the simulation) and questions related to particular tools, Human Machine Interface or other features of the automation. With regard to the experimental exercise, as the evaluation of particular tools and interfaces was out of scope, none questions on these topics have been included.

Another technique included in this category is SPAM (Situation Present Assessment Method), developed specifically for the measurement of ATCOs' SA and whose queries are administered via telephone. The time used to answer the call is used to measure the operator's workload, while the response time to the question is used to assess the operator's SA.

Post-trial subjective rating techniques

These techniques aim to collect the participants' feedback on their perceived situation awareness, giving a SA value on a rating scale. They are usually implemented in the form of post-trial questionnaires and they are frequently used as they are easy and quick to apply, as well as there is a low intrusiveness during the execution of a task. One subjective rating is the Situation Awareness Rating Technique (SART), which is widely used and it was initially created to measure pilots' SA. It is based on the ten dimensions, each of them is valued by the participants on a seven point rating scale (1=Low, 7=High): i) situation familiarity, ii) concentration attention, iii) quality of the information, iv) quantity of the information, v) attention focussing, vi) situation complexity, vii) situation variability, viii) situation instability, ix) arousal and x) spare mental capacity. There is also a reduced SART version composed of just three dimensions (3-D SART) assessing the subject demand and supply of attention and his/her understanding.

CARS is another post-trial technique developed to measure the situation awareness and workload of command and control commanders, whose rating scale goes from 1 (=ideal) to 4 (=worst). This method consists in two group of questions and it takes inputs from Endsley's SA three-level model; the statements of the questions deal with the "ease of identification, understanding and projection of task SA elements (i.e. level 1, 2 and 3 SA)." (Salmon et al. 2006: 18). In addition there is one statement that assess the association correctness between task and goal in the context under analysis. In regard to the workload assessment, this rating technique provides statements to measure the level of difficulty for the subject to "identify, understand, project the future states of the SA related elements in the situation." (Salmon et al. 2006: 18). The QUASA (Quantitative Analysis of Situational Awareness) is a combination of subjective rating and on-line questions that aims to measure the actual and perceived level of SA. To judge the SA level with the on-line probes, participants can choose between "true" or "false", while for their perceived SA they are required to use a rating scale from "very low" to "very high".

Observer rating techniques

In regard to this technique, it is necessary the involvement of a SME, who observes the execution of the task in the working environment and then provides his/her SA analysis in terms of rating score for each subject performing the task. This technique gives a high level of non-intrusiveness and in order to have a SA assessment as effective as possible, it could be more useful to involve more than one SME.

Process indices

The process indices method consists in the measurement of subjects' processes that are used to develop and maintain the situation awareness during the execution of a task. One example of this technique is the use of the eye-tracker, which records the eye movements of the participants to analyse the distribution of the participant's attention in the environment. This method has been criticised for the possibility that the subject might fix the sight on an element without consciously perceiving it, as well as for the difficulty in using the equipment outside of a laboratory context. Another technique which falls into this category is the VPA (Verbal Protocol Analysis) consisting in the development of a written transcript reporting the subject's actions and behaviour through the use of the "think aloud" method. The final aim is to have an overview of the cognitive factors involved in the creation of the subjective situation awareness.

Performance measures

With regard to the performance assessment, the measurement may vary depending on the task under analysis. This technique aims to assess relevant and specific aspects of the subject performance which are considered to have an impact on the level of situation awareness. The advantage of this method is in its ease of application and non-intrusiveness, while a disadvantage can be identified in the definition of the relation between SA and the performance. The latter aspect, in fact, can be noted comparing the performance of an expert ATCO and a novice; the former can have a good performance even if his/her SA is degraded, while the novice can have a high level of SA but at the same time s/he must need to achieve a better performance.

In the following tables, an overview of SA measurement techniques is reported with references to multiple aspects as the domain and time of application, the tool(s) needed and the advantages and disadvantages.

Table 4 - Summary of SA measurement techniques review (Salmon et al. 2006: 22)

Method	Type of method	Domain	Team	SME's required	Training time	Application time	Tools needed	Validation studies	Advantages	Disadvantages
CARS McGuinness & Foy (2000)	Self rating technique	Military (infantry operations)	No	No	Low	Low	Pen and paper	Yes 2	1) Developed for use in infantry environments. 2) Less intrusive than on-line techniques. 3) Quick, easy to use requiring little training.	1) Construct validity questionable. 2) Limited evidence of use and validation. 3) Problems of gathering SA data post-trial e.g. correlation with performance, forgetting low SA periods.
MARS Matthews & Beal (2002)	Self rating technique	Military (infantry operations)	No	No	Low	Low	Pen and paper	Yes 2	1) Developed for use in infantry environments. 2) Less intrusive than on-line techniques. 3) Quick, easy to use requiring little training.	1) Construct validity questionable. 2) Limited evidence of use and validation. 3) Problems of gathering SA data post-trial e.g. correlation with performance, forgetting low SA periods.
SABARS Matthews & Beal (2002)	Observer rating	Military (infantry operations)	No	Yes	High	Med	Pen and paper	Yes 2	1) SABARS behaviours generated from infantry SA requirements exercise. 2) Non-intrusive.	1) Extent to which observers can accurately rate internal construct of SA is questionable. 2) The presence of observers may influence participant behaviour. 3) Access to SME's and field settings is required.
SACRI Hogg et al (1995)	Freeze on-line probe technique	Nuclear Power	No	No	Low	Med	Simulator Computer	Yes 1	1) Removes problems associated with collecting SA data post-trial. 2) Direct approach.	1) Requires expensive simulators. 2) Intrusive to primary task performance. 3) Cannot be applied 'in-the-field'.
SAGAT Endsley (1995b)	Freeze on-line probe technique	Aviation (military)	No	No	Low	Med	Simulator Computer	Yes 10+	1) Direct approach. 2) Subject to numerous validation studies. 3) Removes problems associated with collecting SA data post-trial	1) Requires expensive simulators. 2) Intrusive to primary task. Difficult to see how it would work in C4 environments. 3) Cannot be applied 'in-the-field' or in real-time.
SALSA Hauss & Eyferth (2003)	Freeze on-line probe technique	ATC	No	No	Low	Med	Simulator Computer	Yes 1	1) Removes problems associated with collecting SA data post-trial e.g. correlation with performance, forgetting etc.	1) Requires expensive simulators. 2) Intrusive to primary task performance. 3) Limited use and validation.
SASHA Jeannott, Kelly & Thompson (2003)	Real-time probe technique Post-trial quest	ATC	No	Yes	High	Med	Simulator PC Telephone Pen and paper	No	1) Offers two techniques for the assessment of SA. 2) Administering probes in real-time removes the need for task freezes, and allows the technique to be applied 'in the field'.	1) Probes may direct attention to required elements. 2) Generation of appropriate SA queries places great burden upon analyst/SME. 3) Limited evidence of use or validation studies.
SARS Waag & Houck (1994)	Self rating technique	Aviation (military)	No	No	Low	Low	Pen and paper	Yes 1	1) Quick and easy to use, requiring little training 2) Non-intrusive to primary task. 3) Low cost compared to other techniques.	1) Problems of gathering SA data post-trial e.g. correlation with performance, forgetting low SA. 2) Limited use and validation evidence.
SART Taylor (1990)	Self rating technique	Aviation (military)	No	No	Low	Low	Pen and paper	Yes 10+	1) Quick and easy to administer. Also low cost. 2) Generic – can be used in other domains. 3) Widely used in a number of domains.	1) Problems of gathering SA data post-trial e.g. correlation with performance, forgetting low SA periods. 2) Issues regarding sensitivity of the technique.

Table 5 - Summary of SA measurement techniques review (Salmon et al. 2006: 23)

Method	Type of method	Domain	Team	SME's required	Training time	Application time	Tools needed	Validation studies	Advantages	Disadvantages
SA-SWORD Vidulich & Hughes (1991)	Self rating technique	Aviation	No	No	Low	Low	Pen and paper	Yes 2	1) Easy to learn and use. Also low cost. 2) Generic – can be used in other domains. 3) Useful when comparing two design concepts.	1) Post-trial administration – correlation with performance, forgetting etc. 2) Limited use and validation evidence. 3) Does not provide a measure of SA.
SPAM Durso et al (1998)	Real-time probe technique	ATC	No	Yes	High	Low	Simulator Computer Telephone	Yes 4	1) No freeze required. 2) Has shown promising results in validation studies. 3) Administering probes in real-time removes the need for task freezes, allowing the technique to be applied 'in the field'.	1) Low construct validity. 2) Limited use. 3) Attention may be directed to required SA elements.
SA requirements analysis Endsley (1993)	SA requirements analysis	Generic	No	Yes	Med	High	Video and audio recording equipment	No	1) The output specifies the elements that comprise operator SA in the scenario under analysis. 2) Output can be used to develop SA measure. 3) The procedure is generic and can be applied in any domain.	1) The procedure is a time consuming one, involving observation, interviews and task analysis. 2) Access to numerous SME's is required for a lengthy period of time. This may prove difficult to gain.
C-SAS Dennehy (1997)	Self rating technique Observer rating technique	Civil aviation	No	Yes	Low	Low	Pen and paper	No	1) Very quick and very easy to use, requiring very little training. 2) C-SAS scales are generic, and can be applied in any domain. 3) Can be used as a self-rating tool and an observer-rating tool.	1) Very unsophisticated measurement tool. 2) No validation evidence associated with the technique. 3) Problems of gathering SA data post-trial e.g. correlation with performance, forgetting low SA periods.
Performance Measures	Performance measure	Generic	No	No	Low	Low	Computer	No	1) Data collection is simplistic. 2) Provides an objective measure if SA. 3) Non-intrusive	1) May not reflect actual level of SA e.g. poor performance may still occur with accurate SA. 2) Indirect assessment of SA. 3) Suffers from diagnosticity and sensitivity problems.
Eye tracker	Process Indices	Generic	No	No	Med	High	Eye Tracking Device Relevant Software PC	No	1) Relatively unintrusive to primary task performance. 2) Can be used to determine which environmental elements are attended to. 3) Widely used.	1) Equipment is temperamental and difficult to operate, cannot be used 'in-the-field' and the data analysis procedure is very time consuming. 2) 'Look but do not see' phenomenon should be considered. 3) Offers only an indirect assessment of SA (Endsley et al 2000).
Verbal Protocol Analysis	Process Indices	Generic	No	No	Med	High	Audio recording equipment Observer Pro + PC	Yes	1) Verbalisations provide a genuine insight into cognitive processes. 2) VPA provides a rich data source (Walker In Press) 3) Simplistic procedure.	1) Data analysis procedure is extremely laborious and time consuming. 2) Prone to bias. 3) Verbal commentary can sometimes serve to change the nature of the task.
QUASA McGuinness (2004)	Probe/Self rating technique	Military	No	No	Low	Low	Pen and paper	Yes	1) Combines subjective ratings with SA probes. 2) Developed specifically for military command and control environments. 3) Provides an assessment of actual participant SA and also their perceived SA (confidence in their SA)	1) Intrusive to primary task performance. 2) Does not cater for teams. 3) Limited evidence of use and validation.

Workload literature review

One of the Human Factor constructs analysed during the experimental exercise with the Tower ATCOs and which is included in this PhD thesis is the workload. Even if this concept has been studied for the past 40 years, the word "workload" appeared in the literature around the 1970's and since now there is not a shared and standard definition of workload, of its dynamics, its mechanisms and of the measurement techniques used to assess the construct. The problem of a common definition depends on the fact that multiple factors determine the formulation of this concept, in fact when dealing with workload it must be considered that "(1) there is an operator, using his or her resources to respond to (2) external physical or cognitive demands to (3) perform a certain task" (Hoonakker et al. 2011: 2). In addition to the above-mentioned three points, there are also other demands, as environmental and organizational aspects, which influence the level of workload experienced by the operators.

The initial debate on and analysis of the workload construct emerged while studying the operators' difficulty in satisfying task requirements in various operational fields and the influence of his/her effort and abilities on the workload, during tasks execution in a complex environmental context. In addition to the effort and the abilities of the operators, also the task characteristics and its difficulty level play a role on the workload measurement.

The term "workload" usually includes the demands required to the subject to execute a task, the subject's effort in accomplishing the task and the consequences produced when the subject performs the task to cope with the demand.

Considering the various aspects characterising the workload, it is considered a multifaceted and multidimensional construct whose multiple definitions seem to deal with one or more of these factors: the operator's individual psychological experience; the amount of tasks and relative work to do; the "time and the particular aspect of time one is concerned with"(Cain 2007: 4-1).

According to Gopher and Dochin "[...] mental workload may be viewed as the difference between the capacities of the information processing system that are required for task performance to satisfy performance expectations and the capacity available at any given time." (1986: 41-3); for Lysaght et al. workload can be explained as "the relative capacity to respond, the emphasis is on predicting what the operator will be able to accomplish in the future." (1989: 27). In Cain's view "Workload can be characterised as a mental construct that reflects the mental strain resulting from performing a task under specific environmental and operational conditions, coupled with the capability of the operator to respond to those demands" (2007: 4-3) and a similar definition is proposed by Backs et al., who affirmed that "Workload is a construct that is used to describe the extent to which an operator has engaged the cognitive and physical resources required for a task performance" (1994: 241). Moreover, Kramer et al. consider this construct as "the cost of performing a task in terms of a reduction in the capacity to perform additional tasks that use the same processing resource." (1987: 255).

Analysing all these different definitions, it is obvious and undeniable that "Workload is a multidimensional and complex construct, that is affected by external task demands, environmental, organizational and psychological factors, and perceptive and cognitive abilities" (Weinger et al. 2004: 1419).

The variety of workload connotations brought to a plurality of workload measurement techniques and even if they can measure different aspects of the workload, they all aim to assess the workload level when an operator executes a task, so that his/her performance and the system design functioning can be predicted and modified to satisfy the operator's requirements. Workload could also help to detect if there is an increasing in the task demand and, thus, an imbalance between the demand and the available operator's resources for that task that could produce a degraded human performance. In addition, this construct can be measured to assess the performance of a system, in order to understand which

human and system interaction aspect(s) in the working environment should be changed and/or improved for a more desirable system design. The very ultimate aim could be summarised as the development of more efficient procedures, the working conditions improvement and, as already said, the design of more effective systems able to support the operator's performance in complex environments.
With regard to the choice and application of workload measurements, the researchers communities have highlighted several concerns that consist in "the lack of ecological validity or context complexity; the lack of subject acceptance, commitment or expertise; the lack of assessment of the effect of strategy shifts both on performance, scheduling, and on the workload measurements themselves." (Cain 2007:4-4). In order to support the selection of the more efficient workload measurement technique to use in a specific context, O' Donnell and Eggemeier (1986) listed a set of criteria which can be summarised as follow:

- Reliability of the method with respect to significant changes in the workload values, as well as to possible variations in task demand and difficulty level;
- Reliability of the method that allows to repeat the measurement in other experimental conditions;
- Diagnostics of the source that can have an impact on the workload and of the different resource demands that can contribute to the workload level;
- Non-intrusiveness of the method and of the equipment used to assess workload, in order to maintain the ecological validity of the task performance;
- Subjects' acceptability of the method;
- Timely rapidity of the method in capturing variations that can be salient for the objectives of the workload assessment;
- Selective sensitivity to the changes in the resources demand related to workload and not to factors that are linked to other aspects of the

performance, as for instance the subject physical ability with respect to other task.

The techniques applied to assess the workload are usually divided in three categories: i) subjective rating scales; ii) performance measures; iii) psychophysiological methods. As there is not a shared definition of workload among the researchers community, these categories assess different aspects that can influence the workload and in this regard, Cain stated that “some measurement techniques may be sensitive to specific components of the workload vector only and insensitive to others. Alternatively, some measures may be sensitive to several dimensions, but they may not be able to differentiate the contributions, resulting in an apparent dissociation of causes and effects.” (2007: 4-6).

Subjective rating scales

This measurement technique is used to assess the subjects’ interpretation of their mental demand experienced during their task performance. These methods are characterised by graphical or numerical scales with two extrema values as references for the subject’s evaluation, but they can be structured with an open-ended scale also, where a reference task is used as starting point to judge other tasks, in relation to the reference one. Moreover, the subjective rating techniques can be divided into i) unidimensional methods (e.g. Overall Workload technique); ii) multidimensional techniques (for instance the SWAT); iii) hierarchical rating scale (e.g. Modified Cooper-Harper).

Here below four methods of this category are described: the SWAT; the NASA-TLX; the DRAWS and IP model.

The **SWAT** (Subjective Workload Assessment Technique) is a multidimensional method initially developed to measure the workload experienced by the pilots in the cockpit and by other actors of the crew-station.

This technique requires the subject to judge his/her workload on three dimensions:

1. Time load, consisting in the amount of available time for the task planning, execution and monitoring;
2. Mental effort, referring to the conscious mental demand necessary to carry on a task; and
3. Psychological stress, reflecting the risk, anxiety, confusion and frustration related to the task execution.

According to the SESAR Human Performance repository, “SWAT uses conjoined measurement and scaling techniques, to combine ordinal level assessments into a single, overall workload score which is a value on an interval scale.” (“Subjective Workload Assessment Technique (SWAT)”: 2012). The SWAT scale is composed of Low, Medium and High rates and each of this judgement value is associated to a score (Low=1, Medium=2 and High=3). This method is structured into two steps:

1. Before the task, the subject combines the workload scales of the three dimensions based on his/her increasing workload perception;
2. During the task, s/he has to score a specific task in relation to the three dimension (e.g. 2,1,1).

The combination provided by the subject has a scale value which is associated to a specific workload value for the assessed task and it is expressed under the form of a score included between 0 and 100.

The **NASA-Task Load IndeX (NASA-TLX)** questionnaire is a standardized multidimensional assessment technique that rates the level of workload perceived by a subject using six dimensions to assess the perceived cognitive workload:

1. Mental demand: How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?
2. Physical demand: How much physical activity was required? Was the task easy or demanding, slack or strenuous?
3. Temporal demand: How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?

4. Performance: How successful were you in performing the task? How satisfied were you with your performance?
5. Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?
6. Frustration: How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

A score from 0 to 100 is obtained on each dimension. Then, a weighting procedure is used to combine the six individual dimension ratings into a global score; this procedure requires a paired comparison task to be performed prior to the workload assessments. The comparison between different paired dimensions requires the subject to choose which dimension contributed to the workload level across all pairs of the six dimensions. The number of times a dimension is selected as more relevant represents the weighting of a specific dimension scale with regard to a given task for that subject. Finally, the global workload score from 0 to 100 is obtained for each rated task by multiplying the weight by the individual dimension scale score, summing across scales, and dividing by 15 (the total number of paired comparisons).

DRAWS (Defence Research Agency Workload Scale) technique measures subjects' workload perception in relation to these four dimensions: Input/Central/Output task demands and time pressure, using a rating scale from 0 to 100, even if subjects can judge their workload with a score higher than 100. This method allows to measure the workload level for a single task or for concurrent ones. In relation to this technique, another method has been developed: the POP (Prediction Operator Performance) model which aggregates the single task ratings with the concurrent tasks performance rating.

The **IP** measurement technique aims to assess the workload level through the measurement of the time pressure, which is considered as an aspect of the performance influenced by the individual abilities to cope with the task demands.

The IP model is included in the unidimensional technique category, even if "it considers other factors usually associated with workload (such as strategy selection and individual differences) and uses these factors to moderate time pressure, either by increasing the execution time or by decreasing the amount of time available." (Cain 2007: 4-12).

Performance Measures

The performance measurements include two categories: primary and secondary task measures.

The primary task aims to measure the subject's performance of the main task of an investigation, while the secondary task is used to assess the operator's load and it gives also an indication about the residual capacity of the subject when executing the primary task. In addition, in order to have a reliable primary task, it is necessary to choose a relevant context with a high ecological validity. Wickens (1992)suggested a set of criteria to consider when defining an adequate primary task; according to the researcher a primary task is efficiently designed if the task demands variability can be observed when there are changes in the primary task. In addition, the primary task should not produce other effects (e.g. stress, fatigue) becoming fundamental in the determination of workload during a long period of time and, ast but not least, a primary task should not elicited different impacts on workload and performance from other factors, as for instance the strategies put in place by the operators during the execution of the task.

The secondary tasks is used to allow the subject to adapt the task efforts during his/her performance, so that the primary task seems not to be affected by the secondary one; the demand focus on the secondary ones "shifts the primary task performance into a region where it is sensitive to demand manipulation" (Cain 2007: 4-14) and the decrease of the primary task is assessed while the auxiliary task level of difficulty increases.

Psychophysiological Measures

The psychophysiological measures are objective techniques that aim to assess the subject's psychological state through the measurement of his/her physical state and changes. This category of measures is often useful to detect the workload level if and when the performance and subjective techniques fail in identifying workload variations, due to the impact of the task demand on the objective and perceived operator's workload. In addition, as workload is a multidimensional construct, researchers as Wilson and O'Donnel suggest to implement more than one psychophysiological measurement techniques in order to have a more precise pool of results.

Before the experimental exercise starts, it is fundamental to register the operator baseline state when s/he is not in a stressful context. The baseline is considered as the reference data for the psychophysiological measurement in use, so that the collected information could effectively reflect the subject's starting conditions and the changes in his/her physical and mental states. One of the limitations of this method is related to the intrusiveness of the technical apparatus which is often complex to introduce on the workplace and sometimes difficult to move and carry in a laboratory setting.

Here below some of the psychophysiological measurement techniques used in the research field are reported.

- **Electroencephalography:** this technique is used to collect and analyse data on the subject brain activity through the processing of the waveforms frequency bands. The workload level is obtained by the power between the frequency bands or by the ERP (Event Related Potentials) time shifts. According to Cain, "electroencephalogram measurements showed good correlation with variation in task cognitive demands" (2007: 4-21).
- **Heart Rate:** the measurement of the heart rate includes not only the rate itself, but also its variations and the relative blood pressure value; in addition, as specified by Castor (2003) the reliability of the heart rate value

can be obtained in 30 seconds, while for an optimal value (sensitive also to respiration effects) 5 minutes are sufficient. According to Cain (2007) the physical demands, which can change due to variations in the task difficulty levels, seems to influence the heart rate value more than mental workload.

- **Eye Movement:** the measurement of the eye activity is usually done with the implementation of cameras on a display in front of the subject (as for instance in ATC simulation) or through the use of specific helmet mounted display. Some of the main eye movement aspects to consider are i) the blink activity; ii)the duration of the fixation; iii) the vertical and horizontal movements and iv) the diameter of the pupil. Mental demands has an effect on the eye activity, as well as other factors (e.g. fatigue), thus it is more efficient to use this technique in relation with others and to apply sensors able to detect also small eye movements. With regard to the workload, it has been noted by Castor (2003) that the duration of blink closure seems to diminish when the workload increases; while if the memory tasks and the response effort increase, also the blink latency increases.

4.1.1.2.1.2 Consolidation of final scenarios

The preliminary scenarios were used to capture and consolidate the results of the first analyses, carried out with the interviews and workshop.

Starting from the initial scenarios cards, an advanced version has been detailed with the introduction of complexity factors, which have been combined in each scenario in order to have different difficulty levels for the different flight phases, as one of the purposes of the experimental exercise was to compare the ATCO's performance both in situations of low and high workload. In order to develop a set of scenarios with different level of complexity that could have an impact on the ATCOs' SA and workload, the complexity factors elaborated by Koros et al. (2003) on ATC complexity levels have been taken onto consideration and further adapted to the needs of the scenarios development.

The main categories of complexity factors are sub-divided in more detailed ones. The description and definition of each of the sub-divided factors is provided in the table here below (adapted from Koros et al. 2003):

Table 6 - ATC Complexity Factors (adapted from Koros et al.)

ATC Complexity Factors definition	
1	**Airport Physical Factors**
1.1	Runway/taxiway restrictions
	Unavailable or restricted runways and taxiways impede traffic flow, limiting options, thereby increasing planning, communication, and coordination.
1.2	Non-Visibility areas
	Controllers lose their primary means of gathering information—visual observation. They must rely on other information sources (Air Surface Detection Equipment [ASDE], DBRITE, pilot reports, etc.) to compensate for this loss, adding complexity and workload.
2	**Aircraft/Traffic Characteristics**
2.1	High-traffic volume
	Traffic volume results in high workload (number of tasks, communication, coordination, etc.) and frequency congestion. It requires sustained SA, pushes the limits of the airport, and raises the potential for error. It is especially challenging when it occurs in conjunction with other factors.
2.2	Type of Traffic
	Mixing traffic types raises the likelihood of overtakes, requires sustained SA, and increases the number of speed and heading directives required. As the number of heavy jets increases, wake turbulence requirements can slow the operation.
2.3	Emergency Operations
	These situations are non-routine and require controllers to adjust their priorities dynamically. They increase communication and coordination requirements. Controllers have limited time to gather and prioritize the information.

2.4	Wake Turbulence
	These situations are non-routine and require controllers to adjust their priorities dynamically. They increase communication and coordination requirements. Controllers have limited time to gather and prioritize the information.
3	**Ground Operations**
3.1	Airport Surface Activity
	This can close taxiways and runways, requiring rerouting. This increases communication and coordination requirements and sustained vigilance. Maintenance can lead to a large number of vehicles, multiple runway crossings, removal of airport signs, a mix of vehicle types, unfamiliar users, and other complicating factors.
4	**Weather and Visibility Conditions**
4.1	Visibility conditions
	These conditions require the use of much more restrictive procedures and may be more challenging if these conditions rarely occur. Under these conditions, resequencing aircraft is common. Complexity increases due to the loss of visibility and reliance on alternate information sources.
4.2	Adverse weather conditions
	Workload and complexity increase because of changes in configuration and runway usage. There is increased vectoring, more pilot requests for alternate headings, increased monitoring, and the addition of weather-related activities (e.g., coordination for snow removal vehicles).
5	**Equipment Factors**
5.1	Equipment Malfunctions
	Malfunctions introduce non-routine situations and require the use of standby equipment and procedures. Though rare, the most significant malfunction is the loss of communications.
5.2	Frequency Congestion
	This contributes to blocked transmissions, requiring repeats, increasing workload, and occupying additional controller time. Splitting a busy position is beneficial but results in

	additional coordination.
6	**Distractions**
6.1	Tower Cab Distraction
	Ambient and equipment noise can result in the loss of focus and SA, thereby requiring repeats and increased workload. If not effectively supervised, visitors may block visibility of equipment, restrict movement through the tower cab, or raise noise levels.

The final scenarios have been developed taking into consideration the feedback provided during the interviews and the workshop and from the analysis of the complexity factors.

With regard to the interviews and the workshop, the above suggestions have been implemented in the scenarios:

- Reproduction of the aircraft engine sound;
- Reproduction of the environmental vibrations.

Both the engine sound and the environmental vibrations have been recorded at the tower of "G.B Pastine" airport of Ciampino (Rome) and rendered in the Virtual Reality setting.

The complexity factors that have been considered for the refinement of the scenarios are:

- **Aircraft/Traffic Characteristics:**
    - High-traffic volume
    - Type of Traffic;
    - Emergency situations.
- **Equipment Factors;**
    - Frequency Congestion.

The combination of the above-mentioned elements (workshop feedback and complexity factors) led to the development of the following final set of scenarios (SCN):

- **SCN 1. ATIS information scenario** (v.Easy | v.Hard);
- **SCN 2. VFR position** (v.Easy | v.Hard);
- **SCN 3. NOTAM search** (v.Easy | v.Hard);
- **SCN 4. VFR Circuit Maneuvers** (v.Easy | v.Hard).

The four scenarios had all an Easy and Hard version, where the high traffic volume (i.e. the number of aircraft movements) was manipulated, adding more aircraft movements in the hard conditions. Moreover, an emergency situation was included in the scenario VFR position, and frequency congestion (i.e. noise in the radio system) was added to the scenario VFR Circuit Manoeuvres to modulate the level of complexity between Easy and Hard. In addition, each version was also performed with different sensory conditions (Visual, Visual + Auditory, Visual + Auditory + Vibrotactile and Visual + Vibrotactile) with the aim to assess if the integration of multiple stimuli could have an impact on the subjects' execution of the tasks.
The Tower ATCO while managing the aircraft had also to communicate with the "pseudo-"pilot who had the role of acting in the scenario as a pilot does during real communication with the Tower Air Traffic Controllers. The pseudo-pilot was supported by a sort of script with the communications he had to follow while performing the scenarios in the Virtual Reality. The script gave the possibility to follow a standard guideline for each subject, as all the scenarios and, thus, the oral exchange had to be the same for all the participants in order to be able to compare the subjects' performance.
Here below the description of each scenario is provided.

SCN 1. ATIS information scenario (Easy)	
Scenario description	In this situation the Tower ATCO had to manage the traffic and to provide the updated ATIS message to an aircraft that is landing.
Traffic description	2 commercial airliners: 1 arrival (AA), 1 departure (DA)

SCN 1. ATIS information scenario (Hard)	
Scenario description	The Tower ATCO had to manage the traffic and to provide the updated ATIS message to an aircraft that is landing. In addition there are other aircraft waiting for the authorisation to take-off/landing and the ATCO should make sure the runway is cleared before providing the authorisation for take-off.
Traffic description	3 aircraft: 2 commercial airliners (1 arrival (AA), 1 departure (DA) and 1 light aircraft (ICALZ).

SCN 2. VFR position (Easy)	
Scenario description	A VFR aircraft calls the ATCO requesting to land as there is an emergency on-board (a person with heart attack). ATCO is not able to locate the VFR aircraft and asks pilot to switch on the transponder in order to visualise it on the radar. The ATCO is then able to locate the aircraft and give the pilot the clearance to land and call the ground personnel in charge of the assistance during emergency situations.
Traffic description	1 VFR flight (arrival)

SCN 2. VFR position (Hard)	
Scenario description	A VFR aircraft calls the ATCO requesting to land as there is an emergency on-board (a person with heart attack). ATCO is not able to locate the VFR aircraft and asks pilot to switch on the transponder in order to visualise it on the radar. The ATCO is then able to locate the aircraft and give the pilot the clearance to land and call the ground personnel in charge of the assistance during emergency situations.
Traffic description	2 aircraft: 2 commercial airlines (1 arrival and 1 departure) 1 VFR flight (arrival)

SCN 3. NOTAM search (Easy)

Scenario description	An aircraft calls the ATCO and request the airport NOTAM and the ATCO looks for the NOTAM and provides it to the pilot. Then, he receives a second call from a VFR flight requesting for clearance to take-off.
Traffic description	1 aircraft (departure) 1 VFR flight (departure)

SCN 3. NOTAM search (Hard)	
Scenario description	An aircraft calls the ATCO and request the airport NOTAM and the ATCO looks for the NOTAM and provides it to the pilot. Then it is asked to the ATCO to perform one or more additional tasks as to interact with one VFR aircraft asking for clearance to take-off and an aircraft asking for clearance to land.
Traffic description	2 aircraft: 2 airliners (1 departure and 1 arrival) 1 VFR flight (departure)

SCN 4. VFR Circuit Maneuvers (Easy)	
Scenario description	The ATCO has to sequence 3 VFR flights performing training in the airport circuit and s/he has to monitor the separation between them.
Traffic description	3 VFR flights (call-signs = ICAME, ICETO and ICALZ)

SCN 4. VFR Circuit Maneuvers (Hard)	
Scenario description	ATCO communicates with landing a/c while there are 3 VFR flights performing training in the airport circuit. The ATCO has to sequence the aircraft and to monitor the separation between them. While giving the landing clearance to an a/c the ATCO experiences voice technical failure (i.e. noise in the radio system)
Traffic description	3 VFR flights (call signs = ICAME, ICETO and ICALZ) 1 aircraft (departure) commercial airliner

4.1.1.2.2 Execution and results

The experimental protocol, developed inside the MOTO project, had the aim to analyse if and how the visual, vibrotactile and auditory stimuli, provided both in isolation and in combined sequences, could impact on the ATCOs performance in a Virtual Reality setting.

In particular the hypothesis addressed with the protocol was:

- The combination of the visual, auditory and vibrotactile stimuli improves the subject's situation awareness, workload and performance compared to other conditions (i.e. visual, visual + auditory, visual + vibrotactile) during Tower Operations;

The details of the experimental protocol are provided in the table below.

Table 7 - Experimental protocol

Time (duration)	Phases	Activities
35 min	1. INTRODUCTION	• Welcome and Introduction • Questions and Answers • ATCO to complete consent Form and Biographical questionnaire • Setting up the participants
15 min	2. FAMILIARISATION	• ATCO familiarisation with VR environment and controls • NOTAM reading (briefing)
5 min	3. BASELINE	• Resting state Open eyes (1 min) • Resting state Closed eyes (1 min) • Baseline Scenario (3 min) • Neurophysiological baseline measurement
35 min	4. REMOTE TOWER SCENARIOS (part 1)	Easy Scenarios block (switched order between participants) ▪ V (or VA or VAV or VV) ▪ Post-run questionnaire ▪ VA (or V or VAV or VV) ▪ Post-run questionnaire ▪ VAV (or VA or V or VV) ▪ Post-run questionnaire

		▪ VV (or VA or V or V) ▪ Post-run questionnaire
5 min	Break	
35 min	5. REMOTE TOWER SCENARIOS (part 2)	Hard Scenarios block (switched order between participants) ▪ V (or VA or VAV or VV) ▪ Post-run questionnaire ▪ VA (or V or VAV or VV) ▪ Post-run questionnaire ▪ VAV (or VA or V or VV) ▪ Post-run questionnaire ▪ VV (or VA or V or V) ▪ Post-run questionnaire
4 min	6. SENSE OF PRESENCE BASELINE	Objective measure of the sense of presence. Participant experiencing a scenario with a virtual aircraft suddenly approaching the tower.
5 min	7. FINAL QUESTIONNAIRE	▪ Final questionnaire (Sense of Presence)
2:30 min		

The experiment had duration of two weeks and it has been performed at the "Santa Lucia" foundation in Rome, in the scientific research facility of "Sapienza" University of Rome, where a Virtual Reality setting has been developed. The setting was composed of two mainly positions: one for the experimenter and a Subject Matter Expert (SME), also acting as pseudo-pilot and the other for the subject involved in the test.

The subjects involved in the exercise were 12 working Tower ATCOs or individuals with previous working experience in the Tower Control, in particular in two different types of Tower Control environment:

1. Small towers that are generally less isolated from the airport environment (e.g. the "G.B Pastine" airport of Ciampino (Rome), the airport of Venice

"Marco-Polo di Tessera" - Italy); and

2. Medium and large towers, which are more isolated from the airport environment (e.g. "Leonardo Da Vinci" airport of Rome or "Milano-Malpensa" airport in Milan).

The experimental setting recreated 8 different remote tower scenarios rendered using the head mounted HTC Vive display system. Each scenario was characterised by two task difficulties (Easy and Hard) and four different sensory conditions: i) Visual; ii) Visual and Auditory; iii) Visual and Vibrotactile; and iv) Visual, Auditory and Vibrotactile. The controllers were asked to perform one or more monitoring and/or controlling tasks, as if he/she was acting in real tower control situations. In order to avoid any confound in results due to a fixed events order, the scenarios have been implemented in a different conditions sequence.

During the test the subject had to execute routine tasks of tower control which included also the communication with the pseudo-pilot, in order to reproduce a realistic interaction. At the end of each exercise, the subjects have been asked to complete the questionnaires for situation awareness and workload.

The pseudo-pilot was an Air Traffic Controller and he acted also as Subject Matter Expert (SME), who had the responsibility for the assessment of the subjects' performance after each scenario, filling in a questionnaire specifically prepared for his/her role in this experiment. The involvement of air traffic control experts aimed to adopt a more realistic approach for the experimental protocol validation.

The experimenter placed side by side to the SME had the task of manipulating the virtual environment during the scenarios; in particular he had to start the aircraft movements in the VR with which the subject had to interact, as in the real world. Other three experimenters followed these sessions with the aim to introduce the experiment and its objectives to each subject, to give the questionnaires both to the SME and to the subjects at the end of each scenario and to prepare the equipment to measure the brain activity.

The visual and acoustic information reproduced in the simulated environment were recorded from the top of the Air Traffic Control Tower of the Italian airport of Ciampino, "G.B Pastine" (Rome), enriched the virtual environment. As this Italian airport does not have an insulated tower building, it was possible to record the environmental sound (e.g. aircraft's engine) and the vibrotactile information (e.g. wind speed) during the recording sessions that had the scope to gather the real airport auditory stimuli to be reproduced in the VR platform.

The immersive environment reproduced the interior of a tower building and also the area including the runways and taxiways of the airport which is under the Tower Air Traffic Controllers' responsibility.

In the interior of the virtual tower, the Controller Working Position (CWP) was recreated including the virtual reproduction of the devices that the controllers use in current operations. Specifically, for the experimental exercise purposes, the following devices have been developed as elements of the Virtual Reality platform:

- Display with information on the weather and on the runway in use;
- Tool with the NOTAM[10] information (e.g. restriction of traffic area during specific hours of the day);
- Electronic Paper Strips (EPS) where the information on the aircraft number, speed, route, destination and etc. are provided;
- Telephone and microphone for the communications with the pilots, the ground and airport personnel;
- Air and Surface Movement Radar.

The following image provides an idea of the VR setting.

[10] Unclassified advisories that contain information on the availability of the airport and of the airspace to be communicated to pilots, to alert them of potential hazards.

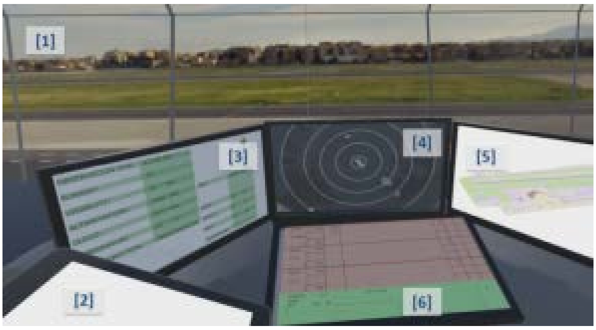


Figure 13 - Virtual Reality setting, [1] external view of the airport, [2] NOTAM tool, [3] Weather and runway information, [4] Air Radar, [5] Surface Movement Radar, [6] Electronic Flight Strips

With regard to my involvement in this activity and in regard to the work done for the PhD thesis, I was in charge of the identification of the Situation Awareness (SA) questionnaire to be used after each run and in addition I carried out the analysis of the results of both the questionnaires of SA and of workload.

The table below summarizes the methods and techniques that have been implemented for the assessment of workload and situation awareness.

Table 8 - Methods and Techniques of the experimental exercise

What	Subjective metrics	When
Situation Awareness	• Adapted version of SASHA questionnaire • SME questionnaire	Post run
Cognitive Workload	• NASA-TLX • SME questionnaire	Post run

Moreover, direct and non-intrusive over-the-shoulder observation has been carried out by human factors experts during the experimental sessions. This technique mainly enables addressing topics related to Human Performance, with the purpose to provide detailed and reliable information on the way the tasks are executed by the subjects. Direct observation allows gathering a high amount of data, especially qualitative data, which cannot be collected using other methods. Debriefings, questionnaires and over-the-shoulders observations are interconnected techniques.

This combination of techniques can complement and reinforce the quality of the quantitative data collected and contributes to analyse more accurate results.

The first results coming from the subjective questionnaire analysis and SMEs evaluation have been reported in the following paragraph.

It is necessary to specify that this data represent more the identification of a tendency than a statistical evidence, due to the low number of involved subjects (i.e. 12 Air Traffic Controllers). Additional experimental sessions and analysis would be needed in order to confirm this first pool of results. These trends have been taking into account only as inputs and not as statistical data for the definition of which multiple sensory modalities combination to select in order to efficiently support ATCOs' performance within a RTO context (see Table 1).

4.1.1.2.2.1 Situation Awareness

With regard to the Situation Awareness, the values that the subjects attributed to the following statements have been recoded, taking into consideration what is stated in the EUROCONTROL document on the SASHA questionnaire (2003: 28):

- *I started to focus on a single problem or a specific area of the sector;*
- *There was a risk of forgetting something important (like transferring an a/c on time or communicating a change to an adjacent sector);*
- *I was surprised by an event I did not expect.*

The reason of the recoding is that in the EUROCONTROL document, these statements are considered as "indicators of poor or degrading SA" (2003: 28).

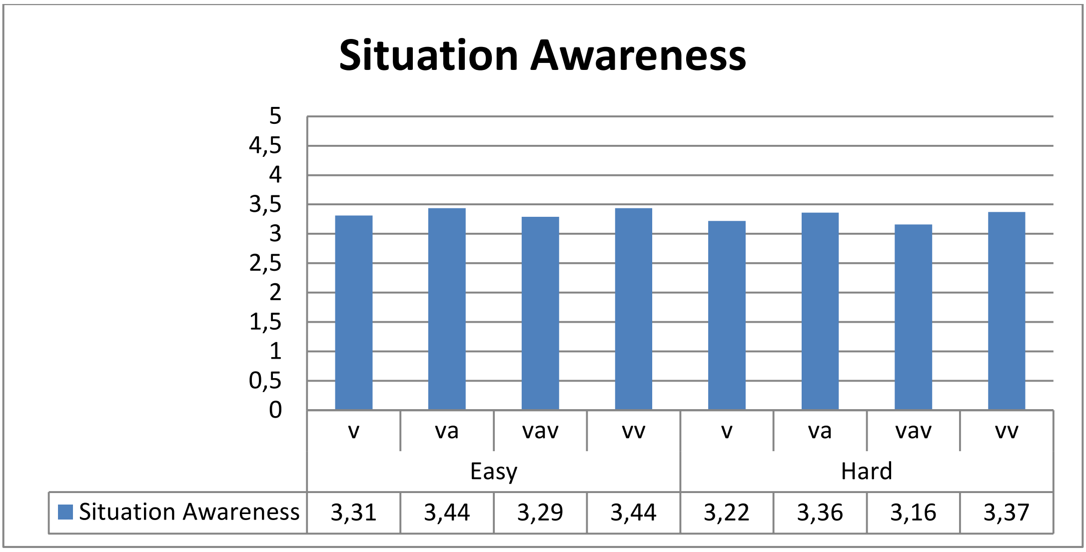


Figure 14 - SA results for all the sensory modality and both Easy and Hard levels

The data analysis highlighted that the highest value of SA results in the combination of the Visual + Auditory and Visual + Vibrotactile modalities. On the other hand, when providing the subjects with the three stimuli at the same time (Visual + Auditory + Vibrotactile), the value of the situation awareness is slightly low compared to the values of SA for those situations where the subjects receive just one modality (Visual) as input, both for the easy and the hard scenarios. In addition, the difference between the Visual and the Visual + Auditory + Vibrotactile modalities increases in the hard scenarios; this can be related to the fact that when the subjects has to handle a highest traffic volume, the three modalities can distract him from the main task, thus resulting in a decreasing of the SA level.

It can be added that when there is a low amount of information to be managed (Easy scenarios), the combination of three modalities did not affect the Situation Awareness with respect to the Visual one as much as in the Hard scenarios. This could be due to the fact that in the Hard scenarios, the Visual + Auditory + Vibrotactile stimuli do not provide additional relevant information for the execution of task. This result is supported by the data obtained for the question "*How would you rate your overall SA during the run?*" that was used to measure the subjects' assessment of their overall level of Situation Awareness, both for the Easy and the Hard scenarios.

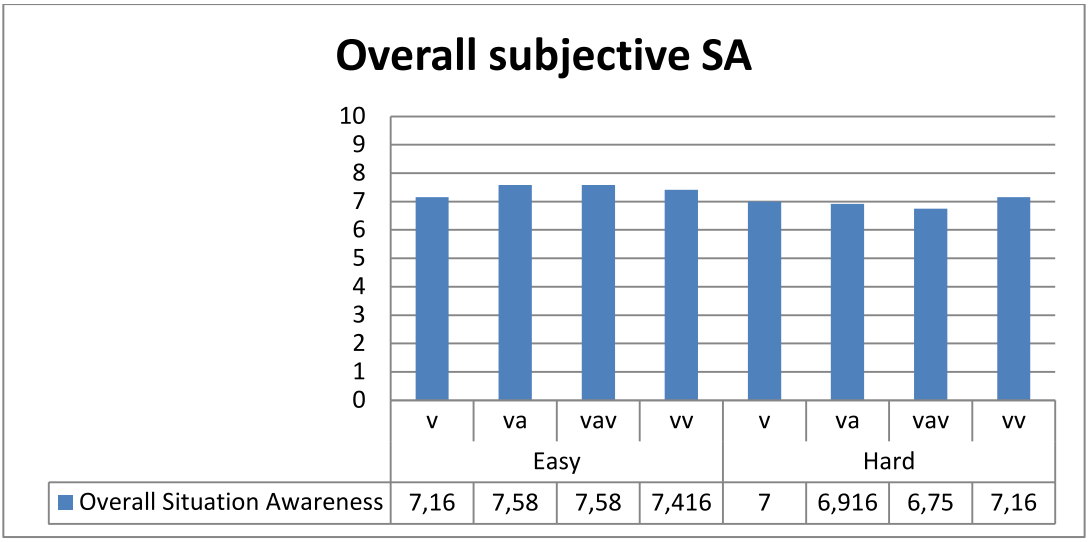


Figure 15 - Overall Situation Awareness assessed by the subjects

In regard to the Hard scenarios, the values for the Visual + Auditory + Vibrotactile modality are lower than all the other modalities; this result can depend on the fact that, as already said, the combination of more than two stimuli might draw attention on other information that is not relevant for the execution of a specific task.

In addition, the subjects evaluated their overall SA as highest for the Visual + Auditory and for the Visual + Auditory + Vibrotactile in the Easy scenarios, followed by the Visual + Vibrotactile and finally by the Visual modality. This can suggest that during the execution of tasks in situations with a low traffic volume, the combination of multiple stimuli might support the operator in maintaining a more acceptable level of SA.

In addition a comparison between the average values of all the modalities for the

Easy and Hard scenarios have been obtained and it is reported in the following graph:

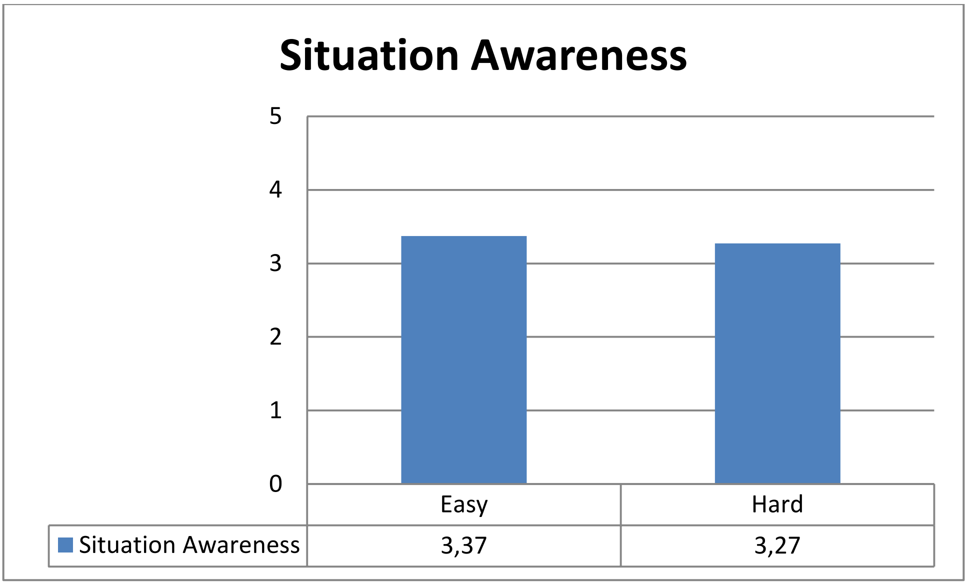


Figure 16 - Comparison between levels of complexity

The comparison shows that there is a difference between the total Situation Awareness for the two complexity levels, thus suggesting that the elements of the scenarios have been well balanced for the measurements of the operator's situation awareness in scenarios with distinct levels of difficulty.

4.1.1.2.2.2 Perceived Cognitive Workload

The analysis of the questionnaire results on the perceived cognitive workload demonstrated that there was an effective difference between the Easy and Hard scenarios. As the figure below shows, the level of workload perceived by the subjects was highest during the Hard conditions, thus meaning that the scenarios have a balanced level of complexity.

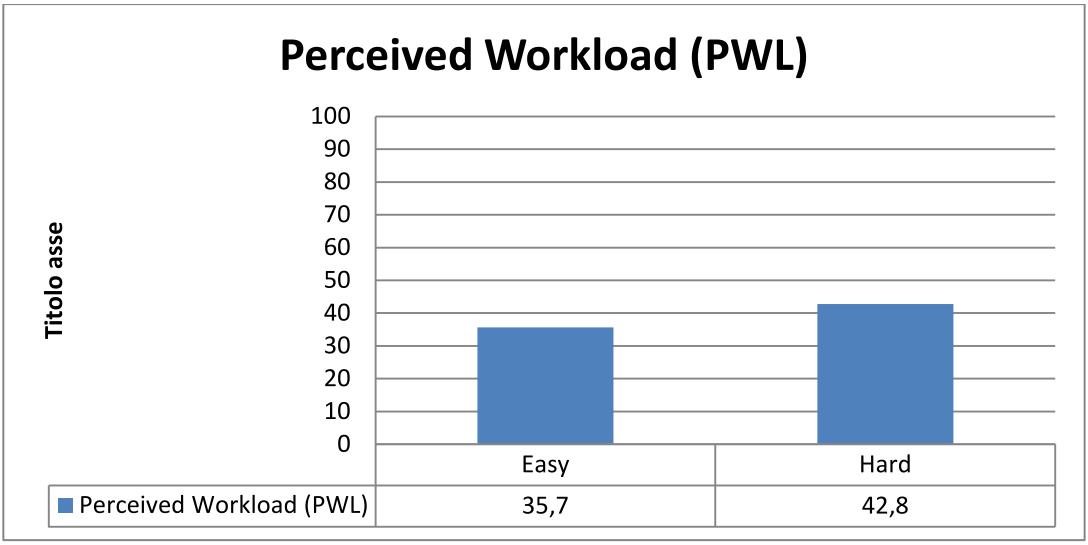


Figure 17 - Perceived Workload (PWL) for complexity level (Easy and Hard)

The value of each level of complexity was calculated by obtaining the average of the weighted values of all sensory modes for each subject. Once the average values of each subject have been calculated, the averages of the mean values of all modes have been obtained, both for the Easy and Hard level.

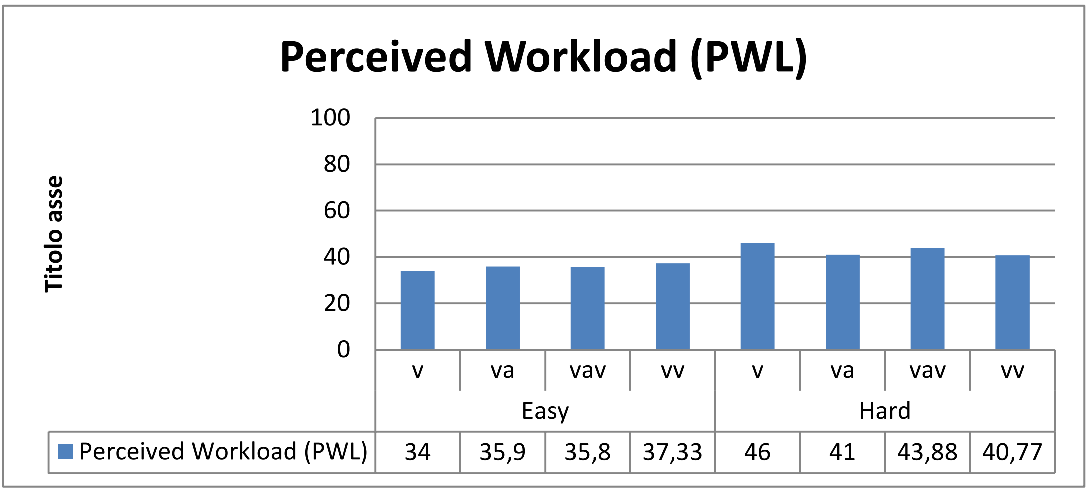


Figure 18 - Perceived Cognitive Workload (PCWL) for sensory modalities and complexity level

It is interesting to note that in the Easy scenarios the workload level for the modality Visual + Vibrotactile is a bit higher than the Visual + Auditory + Vibrotactile modality and this could suggest that when the subject does not have to manage complex situation, the integration of three modalities does not result in an increase of the workload as there is not a specific task requiring a high level of cognitive involvement that can be influenced by the integration of three inputs. On the other side, during the execution of more demanding tasks (Hard scenarios) the combination of the three modalities increases the workload with respect to the other modalities: Visual, Visual+Auditory, Visual+Vibrotactile; this result suggests that during the execution of more difficult task it is to be considered that the preferred combination of sensory modalities for the subjects is Visual+Auditory and Visual+Vibrotactile. This tendency should be further tested in additional sessions, in order to confirm or disregard it.

In addition to the above-mentioned analysis, the perceived cognitive workload has been analysed for each dimension of the workload: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration.

The most relevant results are those related to the dimension of the Performance where while in the Easy scenarios, the performance increases in the Visual and in the Visual + Auditory modalities; in the Hard scenarios, the subjects' performance improves for the Visual + Auditory and Visual + Vibrotactile. This suggests that when the operator has to handle more demanding situations in terms of number of aircraft to be managed, the provision of just one modality could not give the ATCO all the necessary information needed to complete the task.

On the contrary, by mixing and providing ATCOs with Visual, Auditory and Vibrotactile stimuli at the same time, it seems to induce a degradation of performance; this might be produced by the presence of too many stimuli, which can distract the subject, instead of providing informative contents, as the figure below shows.

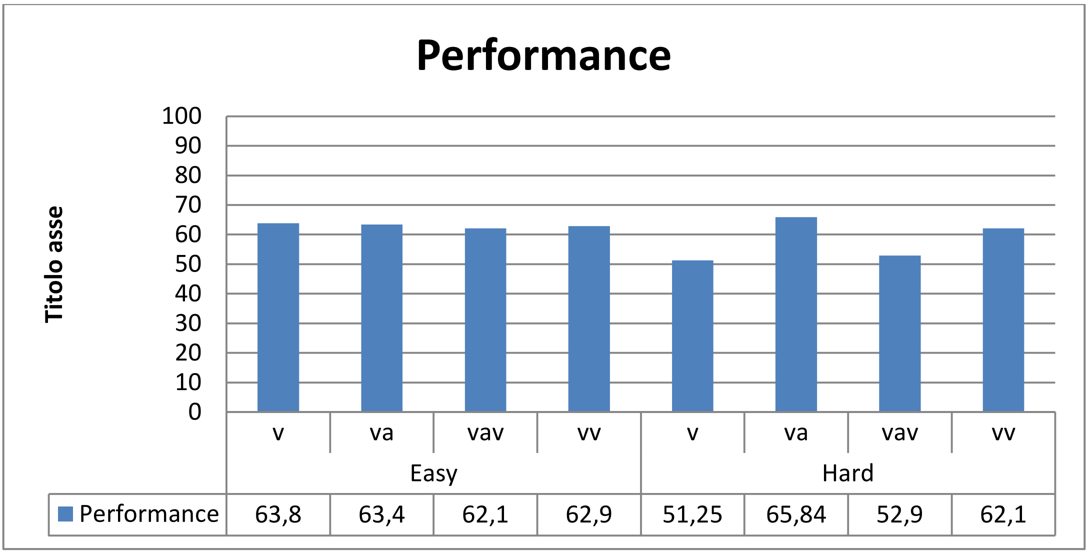


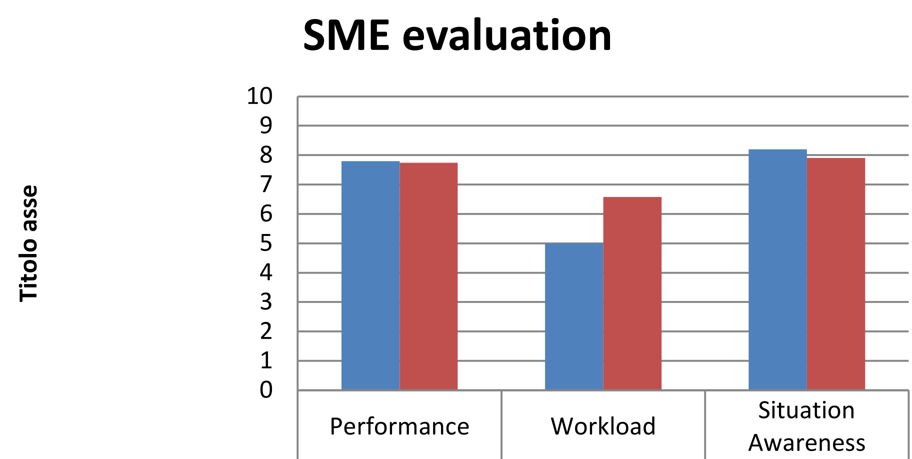
Figure 19 - Perceived Cognitive Workload (PCWL) with relation to the Performance

4.1.1.2.2.3 Subject Matter Expert evaluation

The evaluation of the Subject Matter Expert did not take into consideration the different sensory modalities implemented in each scenario, as the SME assessment aimed to compare the subjects' execution of the tasks in the Easy scenarios and in the Hard ones.

As previously stated, the Subject Matter Expert had to evaluate the subject's execution of tasks at the end of each run to measure the following aspects:

- Overall Performance;
- Overall Workload;
- Overall Situation Awareness.



	Performance	Workload	Situation Awareness
SME evaluation EASY	7,8	5	8,2
SME evaluation HARD	7,74	6,58	7,9

Figure 20 - Comparison between Overall Performance/Workload in Easy and Hard scenarios

The analysis of the results demonstrated that in the Easy scenarios the subjects' overall performance and situation awareness values are highest compared to the Hard scenarios; and the workload level is lowest in the Easy scenarios, if compared to the Hard situations. This evidence demonstrates that the complexity level, Easy and Hard, have been efficiently design and that the results related to the different sensory modalities can be compared with respect to the difficulty level. In addition the scenarios and their complexity levels could be used as reference for the development of new scenarios, through the manipulation of the different elements introduced in each run, in order to create the difficulty levels (see 4.3)

4.1.1.3 Discussion

This experimental exercise did not confirm the initial hypothesis, arguing that the combination of three different modalities could improve the situation awareness and workload of the subjects; in fact the results demonstrated that the preferred modalities combination are mainly the Visual+Auditory and Visual+Vibrotactile ones, especially for the Hard scenarios.

There is only one case in which the three modalities (Visual + Auditory + Vibrotactile) stimuli had a higher value than one of the preferred modality (Visual +Vibrotactile) and it refers to the result of workload and to the evaluation of the overall SA by the subjects (Figure 13) in the Easy scenarios. As previously explained, this could depend on the fact that while controlling a low volume of traffic, the three modalities can better support the operator in maintaining a low level of workload and to be prepared to the next tasks. Considering also the inputs of the participants to the first workshop (4.2.2), the sound of the aircraft engines can help the operator to be aware of the sequence of movements to be controlled in a period of time, meaning that the auditory information can give a support in anticipating a task. The difference between the Visual + Vibrotactile and Visual + Auditory + Vibrotactile information, in fact, is in the absence of the auditory stimulus and, thus, in the Visual + Vibrotactile Easy scenarios, the operator could experience a lack of the sound support in anticipating the subsequent movements.

The overall results have been taken into consideration as a tendency, instead of statistical data, for the phase of concepts design, when deciding which sensory modalities combine to create the most efficient and feasible multimodal interaction in scenarios of Multiple Remote Tower control (5.3.1.1).

One of the major difficulties concerning the experimental exercises was the recruitment of the subjects that could be attributed from one side to the length of the experimental exercise (around 2 hours and half) and to the specific role required for the test, Tower Air Traffic Controllers mainly working in Rome where the experiment was carried out.

In order to reproduce an acceptable level of realism it is fundamental to analyse the main operational characteristics of the environment. The analysis should bring out the main aspects to be implemented in Virtual Reality through iterative processes, involving actual operational experts. In this regard, the feedback of the ATM experts for the definition of the final set of experimental scenarios contributed decisively to the increase of the level of ATM task realism and coherency for the subjects involved in the exercise.

4.1.1.3 Inspirational Benchmark

The inspirational benchmarking scope was the exploration and identification of multimodal interactions and technologies from domains different from ATM or with some aspects in common with the ATM field in terms of level of complexity, type of activities involved, potential use of technological solutions and interaction models and paradigms. The so-called inspirational benchmarking technique is a key activity for familiarization with the preliminary brief that through the collection of information from multiple domains with their specific characteristics can be used as preliminary placeholders for the process of design. The examples collected are extrapolated from different fields, ranging from art installation and music, to virtual and augmented reality, to product and interface design. This research took into account the above-mentioned areas in a cross-fertilization perspective: multisensory interaction, data navigation and manipulation, physical interaction and collaboration.

The analysis of this material has highlighted the topic of a disruptive approach, which consists in the exploration of new interaction modalities in RTOs environment based on the multimodality; and an incremental approach that proposes an improvement of the scenarios proposed in the domain literature involving more innovative interaction models in relation to the emerging concept.

The benchmark have been used as a basis for the first workshop held with Human Factors experts in order to inform about the use and context of multimodal interaction and to give inputs to structure the work of the next phases and the material to be used. The material analysed during the workshop comprehends the technologies collected during the web research, videos on multisensory perception, a collection of inspiration articles and video on a shared area on Pinterest.

The following tables present a selection of examples that shows the inspirational technologies and their application in various domains.

Table 9 - Inspirational benchmark examples

Image	
Brief description	The Myo armband is a wearable gesture control and motion control device that lets user take control of the phone, computer, and it is touch-free. Myo reads gestures and motion to let the user control presentation software with a digital pointer and zooming in on slides. It is a touch-free device that allows also to search the web, play music, turn up the volume, switch between applications, and also to control small drones.
Challenge / need / problem	Body interaction with multiple devices.
Potential for ATM	Wearable technology that can support a fluid interaction with one or more devices (e.g. different screens in a Multiple Remote control configuration).
Keywords	Haptic feedback, gesture control.
Reference	http://www.providermag.it/2013/03/02/myo-the-next-generation-of-gesture-control/

Image	
Brief description	SpaceTop is a design and technology solution to combine 2D and 3D interactions in a single desktop workspace. Users can reach inside the screen, and type, click, draw in 2D; in addition they have the possibility to directly manipulate interfaces that float in the 3D space above the keyboard. The user can use his/her dominant hand to scroll through a main document, while using the other hand to flip through a pile of other documents, in the 3D space, to find a piece of text. The user can then drag that piece of text into the main document through the more precise touchpad interaction. The transparent screen allows the user to view floating User Interfaces, both on the screen plane and in the 3D area behind it or on the bottom surface.
Challenge / need / problem	Integration of visual and tactile feedback.
Potential for ATM	A 3D device that can allow the operator to have more physical involvement in the execution of a task with an easy and quick consultation and organisation of visual data through hand manipulation.
Keywords	Augmented Reality, haptic control, gesture manipulation.
Reference	http://leejinha.com/work.html

Image	
Brief description	Media Services can be mediated by shared spaces filled with multiple devices that play different roles. The mobile device acts as a user's ID and also as a controller device. The screens can be used to explore data with multiple people in a room and anyone can participate, bringing their personal devices into this shared interactive experience.
Challenge / need / problem	Connection between devices and sharing of information.
Potential for ATM	A tool or interaction that gives the possibility to share information from remote positions among different actors involved in a task or activity. In addition it can provide more availability of multiple data from different devices.
Keywords	Information sharing, connection, monitoring.
Reference	http://leejinha.com/mediasquare.html

Image	
Brief description	BMW Holo Active Touch Interface acts like a virtual touchscreen between the driver and vehicle. The free-floating display is operated using finger gestures and confirms the commands with what the driver perceives as tactile feedback. The user can use simple gestures performed with an open hand to activate control pads on a panoramic screen in the dashboard without having to touch the control interface. As soon as a fingertip makes contact with one of the virtual control interface, a pulse is emitted and the relevant function is activated.
Challenge / need / problem	Increase driver visual attention to the driving path.
Potential for ATM system	More fluid and quick interaction between different system visualisations when there is the need to manage different kinds of data from multiple devices.
Keywords	Touch interface, gesture control and haptic feedback.
Reference	https://www.press.bmwgroup.com/global/article/detail/T0266649EN/the-bmw-group-at-ces-2017-in-las-vegas-bmw-holoactive-touch:-an-innovative-operating-concept-for-the-interior-of-the-future https://www.youtube.com/watch?v=osdt891KzHc

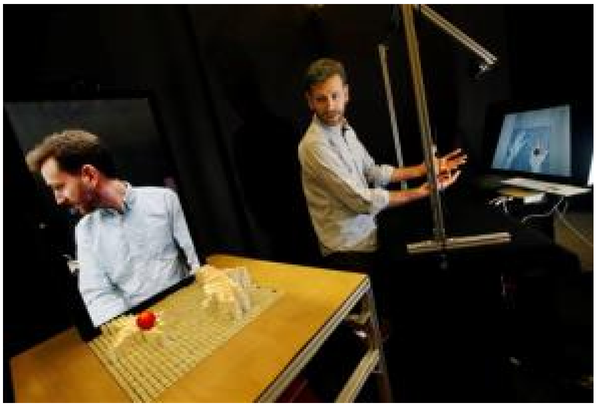
Image	
Brief description	inFORM is a dynamic shape display that can render 3D content physically, so users can interact with digital information in a tangible way. The system can also interact with the surrounding physical world, for example moving objects on the table's surface that moves in accordance with data coming from a Kinect motion sensing input device. In addition, remote participants in a video conference can be displayed physically, allowing for a strong sense of presence and the ability to interact physically from a remote location. People can remotely manipulate objects and physically interact with data or temporary objects.
Challenge / need / problem	Manipulation of objects from a remote position.
Potential for ATM	It can give the opportunity of manipulating and sharing data from remote positions.
Keywords	Tangible interaction and haptic feedback.
Reference	http://tangible.media.mit.edu/project/inform/

Image	
Brief description	The Basslet is a watch-size subwoofer that delivers bass inputs to the user's body, allowing a powerful music experience that headphones alone cannot provide. It provides the power and accuracy of a large sound system in a device that fits on the user's wrist.
Challenge / need / problem	Provide a physical experience of the sound perception.
Potential for ATM	It can support the acquisition and reproduction of auditory information in remote working positions, providing a more immersive experience of audio perception.
Keywords	Auditory information, wearable technology and physical perception.
Reference	https://eu.lofelt.com/ https://www.youtube.com/watch?v=uQ6XjUK7ShI

Image	

	
Brief description	Collide is a synesthetic art installation that transforms recorded motion data into abstract visuals and sound. The idea of this installation came from the phenomenon of synaesthesia, the union of senses. The art installation consists of original chamber music and painterly visuals that reproduce recorded motion data and it represents a sort of conductor of the music composed for the installation. The subject is immersed in a multisensory creative process, where he/she can experience the combination of senses becoming one.
Challenge / need / problem	Render auditory data as visual information to involve the user in the artistic exhibition.
Potential for ATM	The integration of auditory information and visual representations can be used to associate an image (e.g. aircraft) and a sound (e.g. engine sound) related to one of the remote environment controlled in a multiple configuration.
Keywords	Auditory data, immersive experience.
Reference	http://onformative.com/work/collide

Image	
Brief description	KUKA Brand experience is an impressive audio-visual showroom with robotics systems that the user can touch and play with. A tracking system adapts the soundtrack to the user's movements, e.g. once in the room the showroom "wakes up" with sound outputs, and when reaching the centre of the room, two robots appear and the user can start their choreographies by pushing a button on an interface.
Challenge / need / problem	Provide the user with an immersive experience with art installation that reproduces sounds in accordance with the user's movements.
Potential for ATM	The auditory information that follows the user's movements can be helpful in a multiple configuration, to identify the direction of a stimulus and the related environment needing the operator's attention.
Keywords	Spatial sound, physical interaction.
Reference	http://klingklangklong.com/kuka-brand-experience.html

Image	
Brief description	GM's Safety Alert Seat is a system linked to the vehicle crash-alert systems and it alerts the driver of potential traffic danger, by means of directional vibration pulses from the seat. If the computer "sees" the user is wandering out of the lane (without your turn signal on), it will cause the seat to vibrate on the side you are wandering toward. Moreover, when the system detects another vehicle getting close at an unsafe speed, it will alert the driver with an appropriate amount of vibration associated to warning lights and chimes.
Challenge / need / problem	• Provide high level of situation awareness to the driver; • Prevent the risk of collision with other vehicles.
Potential for ATM	The vibration in the chair can alert the operator when an element needs its attention in a specific event. In addition the vibration can be spatialised based on the source and direction of the information (e.g. in a multiple remote control configuration).
Keywords	Haptic feedback, alert system, acquisition of information.
Reference	http://www.gmc.com/safety-features.html

Image	 
Brief description	Token Ring is a wearable device that is activated with fingerprint scan once the user wears it and it is locked when it is taken off. It allows using personal data in multiple situations (e.g. for payment on a bus or in a shop, with home devices like open/close the door).
Challenge / need / problem	• Secure user credentials; • Use a wearable tool to control home devices; • Secure storage of personal data and easier interaction with personal devices.
Potential for ATM	It allows the operator to control devices with simple and efficient gesture control and to access to the supporting tools in the working position.
Keywords	Wearable technology, connection, interactivity, gesture control.
Reference	https://tokenize.com/#home-top

4.1.1.4 Preliminary multimodal interactions definition

The first workshop involved 4 Human Factors experts and had the purpose of discussing the potentialities of the multisensory integration in a remote tower environment and to define initial examples of control tower situations where this integration can provide potential benefits to the ATCOs' performance.

The workshop started with a meeting objectives introduction, then the benchmark with inspirational technologies coming from multiple domains were illustrated together with the potential use of these technologies in the ATM scenarios. At this phase of the process, the scenarios have not been detailed in depth, in order not to introduce limitations to the participants' ideas and proposals coming also from different domains interested by multimodal interaction (e.g. videogames, art exhibition etc.).

Starting from the design principles of the five categories (see Table 8) additional ideas coming from existing multimodal technologies and interactions have been brought to the attention of the workshop participants.

The results of the workshop were preliminary ideas of multimodal interactions and tools to be explored for RTOs scenarios and they are reported here below:

- **Microphone with vibration**: a tool able to provide the user with information on activities or events that could negatively impact on the operators' performance;
- **Weather and aircraft information integration**: Interface which combines data on the weather conditions and the vehicles movements, implementing visual and auditory inputs;
- **Sound spatialisation (3D audio):** aircraft physical distance represented with a manipulation of the sound levels;
- **Aircraft frequency**: distinct level of sound associated to different radio frequency, provide specific information to the ATCO;

- **Wearable vibration:** vibrotactile inputs is used during the communication between different actors (e.g. pilot-TWR operator and TWR operator-pilot; TWR operator-ground personnel and ground personnel-TWR operator, etc.) and for each kind of oral exchange, the intensity and the characteristics of the vibration change;
- **Strategic organisation of trajectories**: a touch interface enabling the operator to “draws” the trajectory, receiving a visual (trajectory path) and a haptic feedback based on the level of feasibility of the trajectory chosen;
- **Parallax effect functionality:** this is more an aspect to be considered when designing an interface, in order to allow the operator to be aware of the right aircraft position with respect to the runway and taxiway orientation.

These initial inputs have been taken into consideration to develop a preliminary set of interactions (see Table 10) hypotheses on the potential benefits the designed solutions could bring.

These preliminary examples of multimodal interactions in RTOs have been discussed during a second workshop with 5 Human Factors experts, 1 illustrator and 1 graphic designer. The objectives and results of the workshop are described in the following section.

In the next phase, these preliminary exploratory concepts have been further developed and they have been integrated in more detailed scenarios of Remote Tower Operations (with respect to the first version), also providing additional specifications on the potential interaction characteristics between the target users, the tools and the environment during the execution of ATM tasks.

Table 10 - First set of multimodal interactions

SCENARIO	TASK	INTERACTION	EXPECTED BENEFITS
Aircraft movement from the three airports	**Manage the movements in the three airports**	**User Experience (UX): Transition between three virtual environments** **User Interface (UI):** - The virtual environments must be distinguishable - The user must have the possibility to adapt the UI to his/her activity	Improvement of situation awareness about the flight traffic of each environment
When controlling the multiple environments the TWR ATCO organize the Flight Progress Strips	**Manage the Flight Paper Strips of the multiple airports**	**UX: Interaction with the Flight Progress Strips** **UI:** - The Flight Progress Strips of each airport must be distinguishable - The difference between the Flight Progress Strips of each environment must be clear and easy-to-understand - The UI must have dedicated area for the strips of each airport - The UI must show the strips in the foreground base don't he user's needs	More easy and quick organisation of the flight strips, due to the difference between strips related to each airport
A ground vehicle calls the ATCO to ask the authorisation for an inspection on the runway	**Remember that the runway is occupied by the ground personnel**	**UX: Remember an underway process** **UI:** - The UI must notify the ground personnel request of inspection to the ATCO - The runway status must be visible to the ATCO during the time of the inspection - The UI must notify the ATCO when the runway is clear	Increase the situation awareness and decrease the possibility of error, due to the forgetfulness of the inspection in progress on the runway
There is a period of inactivity at the airports and the Tower operator plan the aircraft	**Trajectories planning**	**UX: Manipulation of a virtual environment** **UI:** - The UI must show the map of the area under the responsibility of the TWR ATCOs	Improve of the situation awareness, due to an efficient and easy to use tool/function for the planning phase

movements to the stands		- The user must have the possibility to manipulate the interface - The UI must show the trajectories the TWR ATCOs "draws" on the interface	
An aircraft call the TWR ATCO for an emergency landing	**Manage an emergency**	**UX: Notification of an emergency** **UI:** - The UI must render the aircraft engine sounds in the headphones - The UI must provide a visual output of the aircraft engine sound	Increase of the time-reaction when an emergence occurs
An aircraft call the TWR ATCO to ask information on the weather conditions	**Collection and communication of the meteo data to the pilot**	**UX: Interaction with weather information** **UI:** - The UI should visualize the weather conditions associated to the specific area of interest - The visual information should be associated to an auditory input	Enhance the information sharing of important information for the efficient conduct of the flight

4.1.2 Step 2 – Concept generation

This phase had the goal of identifying the core concepts to be explored and iteratively refined until achieving the final version to develop in the form of a micro-scenario with the multimodal interaction in the context of use. The focus of the concept generation was on the consolidation of the first version of the concepts summarized in Table 10, especially with regard to the interaction modality between the user and the system. In this phase the design of the space and of the interaction have been defined considering the specific ATM domain of the Remote Tower Operations, together with inputs on system interfaces collected from various domains.

From an interaction perspective and user experience point of view, it was crucial to:

- create a consistent solution in term of what is presented to the operator, in order to avoid confusion in the process and/or increase the possibility of error;
- guarantee a level of personalization of the solution and the possibility to calibrate the solution by considering not only the individual ability for instance to work under pressure and/or to manage a certain level of complexity, but also the personal working style;
- Define the boundaries between the conventional Tower Control interaction modalities and the multimodal ones and which triggers activate and modulate the different combinations of sensory stimuli.

The table developed during the previous phase has been improved through an iterative process, which had the aim to add more level of detail to define the different aspects of the interactions. A first improvement of the preliminary set of interactions has been done during the second workshop, where the participants discussed each interaction of *Table 10*, analysing their potentialities and weaknesses, in terms of feasibility and of coherency with the ATCO's working flow in the remote environment. In this regard the different perspectives and background, those of the Human Factors with a deep knowledge of ATM operations and those of the illustrator and the interaction designer with a higher expertise on the development of interfaces, brought to the refinement of the table with a new version, with much more details on the Interaction Modality category.

Table 11 - Second version of th multimodal interaction concepts

NEED	TITLE OF THE INTERACTION	INTERFACE FUNCTIONALITIES	INTERACTION MODALITY	SENSORY CHANNEL	EXPECTED BEENFIT
Manage aircraft and vehicles movements on more than 1 airport	**Transition between 3 airports**	The Controller Working Positions is divided in two spatial sections which represent different airports: 1. Primary airport is on the top in the foreground; 2. The remaining ones are on the bottom in periphery screens in the background.	Among the possible interaction modalities, there is the head rotation associated to an enlargement of the view, which overcomes the 120 degrees.	Visual and proprioception	Improvement of situation awareness about the flight traffic of each environment
		The interfaces of the primary and secondary screens give the ATCO the possibility to always have at his/her disposal the environments to be controlled and to switch from one to another when necessary.	Gesture movement of ATCO's hands and arms to change the airport visualization. The movement could also be supported by a wearable bracelet.		
Monitor the activities and check the runway status at secondary aerodromes	**Overview of a secondary airport**	When the visualization is on the primary aerodrome, the ACTO can give a quick look to one of the secondary airports.	Gesture movement of the arm from the secondary to the master display to have a preview of the secondary screen. The arm movement could be hold until it is necessary for the operator. The airport goes back to the initial configuration when the user moves the arm toward the secondary screen.		
Organize and manipulate the Flight Progress Strips (FPS)	**Interaction with flight strips**	- The Flight Progress Strips of all the controlled airports are clustered on a unique tool, based on the chronological order of movements. - On the FPS the weather information relative to each aerodrome can be reported	Baseline situation, no interaction happening.	Visual	More easy and quick organisation of the flight strips, due to the difference between strips related to each airport
		The FPS can be removed from the strip bay when an aircraft is no longer under ATCO's	Scroll from right to left to remove the strips when the aircraft passes to another	Visual and touch	

		responsibility.	ATM sector.		
		- All the strips are at ATCO disposal and s/he can bring to the foreground those s/he needs - The system allow to take notes on the FPS	- Brief tap on the display to select a strip - Spread and pinch to zoom in and zoom out		
Remember and check the runway status	**Voice recognition**	The voice recognition function allows the system to activate the "inspection modality" when the ATCO authorizes it through the radio frequency. When the airport interested by the inspection is in the foreground, the ATCO can see the car on the runway.	Production of a vocal message	Visual and proprioception	Increase the situation awareness and decrease the possibility of error, due to the forgetfulness of the inspection in progress on the runway
		• The system applies a colored filter on the visualization of the airport with the inspection • The filter remains on the airport display when it is moved to the bottom	Gesture movement of ATCOs hands and arms to change the airport visualization. The movement could also be supported by a wearable bracelet.		
		When the airport interested by the inspection is on the foreground, the system highlights the presence of a vehicle on the runway with an icon or other visual element.	Spread and pinch to zoom in and zoom out.	Visual and touch	
Check and communicate weather information	**Changes in an expected state**	The system/function provides the ATCO with the weather information (e.g. rain from 14pm to 17pm).	Baseline situation, no interaction happening.	Visual	Enhance the information sharing and improve the situation awareness
		The system advices the ATCO of the beginning and end of the rain, respectively at 14pm and 17pm.	Vibration/Short "beep" and sound perception (thunderstorm/gentle rain) activated when there is an expected change in the environment (14pm and 17pm)	Visual and vibrotactile and auditory	
	Changes in an unexpected	The system detects an unexpected change in the environment (e.g. instead of the fog, it	- Vibration/Long "beep" and sound perception (thunderstorm/gentle	Visual and vibrotactile	Enhance the information sharing, the

	state	starts raining) and it informs the ATCO.	rain) notify the unexpected changes - The kind and intensity of vibration and sound vary based on the impact of the unexpected changes on the operations (2 options: reduced or suspended operations)	and auditory	situation awareness and the time reaction
Operate quickly and efficiently to solve an emergency	**Emergency situation**	The system informs the operator of the emergency	- Variation of the brightness intensity of the display with the airport interested by the emergency (T1) - The brightness increases if the ATCO has a low time-reaction (T2) - Additional display (or icon) movement (e.g. shaking, jumping) are activated when the ATCO does not take any decision for a long period of time (T3) - T1, T2 e T3 represent the increase of the level of situation severity (growing intensity) - Vibration coming from the wearable bracelet	Visual, vibrotactile	f Improve the time-reaction and the situation awareness

The interactions described in *Table 11* and the ideas collected during the workshop were the starting points that brought to the development of visual representation of the multimodal interactions.

The first representations have been discussed with two Air Traffic Controllers, who gave their comments on the coherence, usability and the acceptability of the new concepts of interaction. The meeting have been structured in the form of a focus group with 2 Human Factors experts that introduced the concept of Multiple Remote Tower Operations and then, they asked the two participants to try the interactions with a simulated Controller Working Position reproduced using the Wizard of Oz[11] technique.

During this simulation, the HF experts asked questions to gather feedback on the interaction, the answers provided by the subjects have been organised in the following report, structured in sections representing the topics of the discussion (i.e. the multimodal interactions).

- Controller Working Position (CWP);
- Transition between 3 airports;
- Interaction with flight strips and integrated weather info;
- Inspection on the runway;
- Emergency notification;
- Topic of discussion proposed by the participants

The following tools have been used to recreate the CWP where an Air Traffic Controller manages three airports in a Multiple Remote Tower configuration:

- 1 screen (dimension) used as the primary display with the image of the principal controlled airport;
- 4 laptops (2 Lenovo), 1 Samsung and 1 Dell: the Lenovo and the Samsung

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[11] In the human–computer interaction, the Wizard of Oz technique is a research experiment during which subjects interact with a computer system, believing that the system is autonomous, while it is actually totally or partially manipulated by a human being.

have been used as secondary screens; two laptops reported the image of the remote airports, while on the one corresponding to the primary controlled airport, the Surface Movement Radar was reproduced; the Dell where used to manipulate the environment in accordance with the user movements

- 1 Samsung I-pad, where two versions of the Flight Progress Strips (FPS) have been shown: 1 with the strips in horizontal direction and the other in vertical orientation. On the FPS strips it was also integrated the weather icons associated with the rain sound;
- A pair of headphones reproducing the environmental sound (e.g. the rain of one of the three airport);
- 2 plastic bracelets used to simulate the switching from one aerodrome to another.

On the Dell there was a power point presentation with the sequence of images that appeared on the primary screen when the subject performed one of the interactions. For example, for the interaction of the transition between 3 airports, the subject was seating in front of the displays and he had to simulate the switching interaction to pass from one aerodrome to another with a movement of the arm, similar to that shown in the BMW Holographic (5.3.1.2). The subject moved the arm (e.g. from the right to the left) to change the screen visualisation on the primary screen. The switching was executed by one of the HF experts, following the sequence of the power point presentation on the Dell connected to the primary screen. The same technique (Wizard of Oz) has been used to simulate the Overview of a secondary screen; while for testing the representation of the FPS has been used the I-pad that the user could interact with, as for example takes not on the strips as the Tower Air Traffic Controllers usually do in their job.

In regard to the Inspection on the runway, it was explained the situation in which on the primary screen a runway inspection occurred and when moving the principal airport to a secondary display, the latter became opaque to remember the

Tower Air traffic Controller that there was an inspection in progress and to consider it while managing the departure and arrival aircrafts on the airport with the inspection.

Concerning the interaction Changes in expected/unexpected event, the user listened the “beep” alerting him of something happens at a specific aerodrome and then, the sound of the rain in the headphones activated by the HF expert was reproduced.

With regard to the Emergency notification interaction, it was not possible to reproduce the vibration and the brightness of the screen, and thus, it was asked to the user to imagine the scenario of an aircraft calling for an emergency landing and to give a feedback on the interaction modality proposed (i.e. the changing brightness and the vibration implementation).

For each topic of discussion a set of questions have been prepared and it is reported here below, followed by the feedback collected from the two ATCOs.

Table 12 - Interview form for the focus group with two ATCOs

Questions
Controller Working Position (CWP)
1. Is it a possible solution to have the visualization of the Surface Movement Radar of the primary airport on the corresponding secondary screen or it is better to have a duplication of the primary display? 2. Is it better to have touch or non-touch secondary screens?
Transition between 2-3 airports
1. Is it a possible solution to use gesture control movements to switch between one airport and another? 2. Is it a possible solution to use wearable bracelets to enable the gesture control movements while switching switch between one airport to another? 3. Is it a good option to have a preview of a secondary airport? Is it better swiping or tapping and holding?
Interaction with flight strips and integrated weather info

1. Is it a good option the integration of a timeline on the Flight Progress Strips interface? 2. Is it better to order the strips horizontally or vertically? 3. Is it a good option to integrate the strips of all the airports on one device? 4. Is better to have also the strips of the secondary airports in a different format or to hide them when controlling the primary aerodrome? 5. Is it a good option the integration of weather info on the Flight Progress Strips interface? 6. Is it a good option to provide the auditory information in different intensity for expected and unexpected changes in the environment? 7. Is it a good option to visually highlight an unexpected change?
Inspection on the runway
1. Is it a good solution to have the voice recognition system for the activation of the "runway inspection modality"? 2. Is it a good option to have a filter on the airport when secondary? 3. Is it a good option to highlight the car?
Emergency notification
1. Is it a good option to increase the brightness to notify the emergency? 2. Is it a good option to add the movement of the display and the vibration?

Report on the multimodal interactions tested with users

In the following paragraphs the results of the discussion are reported in relation to each interaction tested during the discussion.

1. Controller Working Position (CWP)

According to the ATCOs, it was considered a good option to display the Surface Movement Radar on the screen of the primary airport when it is active on the biggest one. In addition also the weather info, the radio frequencies and the NOTAM have been proposed as tools to implement in the secondary screens.

The choice between to have touch screen for the secondary airports was considered dependent on the information to be shown. Specifically, it was suggested that if the

ATCO has to interact with the information displayed on the secondary screen, the display should be touch.

With regard to have the information of all the three airports on one device, the ATCOs' preference was to keep the different towers set up separated along with the instrumentations (e.g. weather information, NOTAM, radio frequencies) and when one airport becomes the primary one, all the related info and tools should move to the central position. The call from the pilot should be the condition to switch the master airport to another one.

It was suggested that the airports should not have a fixed position on the different screens, but that when switching from the master to a secondary airport, the two displays had to exchange their position. This means that if the primary airport is A, when the airport C on the right, for example, becomes the primary, the airport A takes the position of the C on the right display.

2. **Transition between 3 airports**

The implementation of gesture movements with wearable bracelets is a well-accepted option; while the preview of a secondary airport was considered not necessary. The ATCOs preferred to have the secondary airport always on the secondary screens, without any correlation with and transition to the primary one.

In order to give a look to a specific area of the airport, the ATCOs suggested the implementation of a zoom in/out function, in order to have a deeper insight on what it is happening at one of the secondary airports.

3. **Interaction with flight strips and integrated weather info**

The suggestion was to maintain the same configuration as in current operations, meaning that it would be better to have the Flight Progress Strips ordered vertically, instead of horizontally as it was proposed in the new concept.

In addition, it was preferred to have the strips of each airports separated, instead of integrating them in one device.

Moreover, it was considered not necessary to integrate the weather information on the strips, as in current operations there is already a specific meteorological bulletin where the expected and unexpected info is reported.

The provision of the auditory info (the “beep” or other sounds) in different intensity for expected and unexpected changes in the environment was considered an unnecessary redundancy. In ATCOs view, it was sufficient the environmental auditory information provided in the headphones when managing one of the airport in the master display.

The visual highlight of the unexpected change has not been discussed.

4. Inspection on the runway

Concerning the use of a filter on the secondary screen interested by the inspection, the ATCO preferred not to have it. They suggested having the possibility to activate a specific strip (e.g. “Runway occupied” strip) that remains active both when the inspected aerodrome is the primary one and when it is on a secondary screen. This strip must be visible both on the display and on the strip bay of the airport. In addition if the strip notifying the inspection is shown on the display, it could be avoided a function highlighting the car doing the inspection on the runway.

5. Emergency notification

Concerning this interaction, it was suggested that the visual input came from the illumination of the radio frequency channel related to the airport where the emergency is occurring, in order to easily associate the event and the relative airport. It was proposed to combine this input with the volume of the call to notify the emergency situation. In addition it was considered the possibility to adjust the volume, based on the operator’s needs. With regard to the implementation of the vibration, the ATCOs proposed not to integrate it as it could add an unnecessary amount of inputs.

6. Topic of discussion proposed by the participants

During the focus group an additional topic has been discussed, namely the radio communication between the Air Traffic Controllers and the pilots. According to the ATCOs, multiple frequencies can be difficult to handle in a multiple remote tower setting (even if there are 2 frequencies) and it is fundamental to clearly render which frequencies (airport) the ATCO is communicating with, as this factor can have a big impact on the operators' Situation Awareness (SA).

In traditional operations, the communications between the pilots and the ATCO occur via radio and when the ATCO speaks with an aircraft, all the pilots in the same area listen to that communication. With the multiple control, the aircraft receiving the ATS could operate in different areas (e.g. in three different aerodromes), thus from one side the ATCO could be confused by the overlapping of the communication from different airports; from the other side the pilots, listening to the communication with aircraft flying in other areas, could be distracted by information not referring to them.

In order to avoid this risk, the proposed solution was the "spatialisation of the radio frequencies".

This function would consist in differentiate the radio frequency of each aerodrome, making clear the direction which each communication originates from. In practical terms, the radio frequency is active when an airport becomes the primary one, while those of the secondary ones are in standby. If an aircraft from a secondary airport is calling, the ATCO would understand to which aerodrome it corresponds to (the right/left one), based on the side (left/right ear) from which the auditory information is coming and also depending on the characteristics of the voice (e.g. high-low tone, woman/man voice). In addition to this auditory info, also a visual icon would appear at the top of the display notifying that someone is speaking (e.g. sound waves).

If the ATCO needs to start the communication with a secondary airport, s/he would have to rotate his head and to speak directly looking at the specific secondary display where a directional microphone and an icon would recognize someone speaking and in that moment the radio frequency becomes active for that airport. If the system does not catch the message clearly, the colour of the icon and its movement will change (e.g. red); while when the message is clear, the icon will be coloured differently (e.g. green).

The results of the meeting highlighted the necessity of a trade-off between the technological innovation and the ATCOs feedback on the introduction on new interaction modalities in the context of Remote Tower Control of multiple aerodromes, which implies also a reshape of some of the current operational mechanisms. The trade-off was considered fundamental in order to harmonise the tendency toward a technological improvement and a more fluid interaction in the working environment; and the operators' needs of not totally changing their current operational procedures and instruments, otherwise a negative impact on their performance could be the results of a design that does not consider the users' feedback. Considering that, once collected the ATCOs feedback, the *Table 11* has been updated and the visual representations have been refined and then implemented in micro-scenarios, representing the multimodal interactions in use in the operational context, namely the Multiple Remote Tower Control of three airports.

Table 13- Multimodal interactions with additional inputs (red lines) from the ATCOs

NEED	TITLE OF THE INTERACTION	INTERFACE FUNCTIONALITIES	INTERACTION MODALITY	SENSORY CHANNEL	EXPECTED BEENFIT
Manage aircraft and vehicles movements on more than 1 airport	**Controller Working Position**	The Controller Working Positions is divided in two spatial sections which represent different airports: 3. Primary airport is on the top in the foreground; 4. The remaining ones are on the bottom in periphery screens in the background.	Among the possible interaction modalities, there is the head rotation associated to an enlargement of the view, which overcomes the 120 degrees.	Visual and proprioception	Improvement of situation awareness about the flight traffic of each environment
	Transition between 3 airports	The interfaces of the primary and secondary screens give the ATCO the possibility to always have at his/her disposal the environments to be controlled and to switch from one to another when necessary.	Gesture movement of ATCO's hands and arms to change the airport visualization. The movement could also be supported by a wearable bracelet.		
Monitor the activities and check the runway status at secondary aerodromes	**Overview of a secondary airport**	When the visualization is on the primary aerodrome, the ACTO can give a quick look to one of the secondary airports.	1st option: Gesture movement of the arm from the secondary to the master display to have a preview of the secondary screen. The arm movement could be hold until it is necessary for the operator. The airport goes back to the initial configuration when the user moves the arm toward the secondary screen.		

			2nd option: The same action (check the status of a secondary airport) can be done with the touch interaction directly on the secondary screen		
Organize and manipulate the Flight Progress Strips (FPS)	**Interaction with flight strips**	1st option: The Flight Progress Strips of all the controlled airports are clustered on a unique tool, based on the chronological order of movements. 2nd option: The Flight Progress Strips of each airport are separated on different strips bay in the dashboard. - On the FPS the weather information relative to each aerodrome can be reported	Baseline situation, no interaction happening.	Visual	More easy and quick organisation of the flight strips, due to the difference between strips related to each airport
		- All the strips are at ATCO disposal and s/he can bring to the foreground those s/he needs - The system allow to take notes on the FPS	- Brief tap on the display to select a strip - Spread and pinch to zoom in and zoom out	Visual and touch	
		The FPS can be removed from the strip bay when an aircraft is no longer under ATCO's responsibility.	Scroll from right to left to remove the strips when the aircraft passes to another ATM sector.		

Remember and check the runway status	**Voice recognition**	The voice recognition function allows the system to activate the “inspection modality” when the ATCO authorizes it through the radio frequency. When the airport interested by the inspection is in the foreground, the ATCO can see the car on the runway.	Production of a vocal message	Visual and proprioception	Increase the situation awareness and decrease the possibility of error, due to the forgetfulness of the inspection in progress on the runway
		<u>1st option:</u> - The system applies a colored filter on the visualization of the airport with the inspection 2nd option: - The system applies a coloured cover on the visualization of the airport with the inspection <u>Both the options</u> The filter remains on the airport display when it is moved to the bottom	Gesture movement of ATCOs hands and arms to change the airport visualization. The movement could also be supported by a wearable bracelet.		
		When the airport interested by the inspection is on the foreground, the system highlights the presence of a vehicle on the runway with an icon or other visual element.	Spread and pinch to zoom in and zoom out.	Visual and touch	
Check and communicate weather informatio	**Changes in an expected state**	The system/function provides the ATCO with the weather information (e.g. rain from 14pm to 17pm).	Baseline situation, no interaction happening.	Visual	Enhance the information sharing and improve the situation
		The system advices the ATCO of the	Vibration~~/Short “beep”~~ and	Visual and	

n		beginning and end of the rain, respectively at 14pm and 17pm.	sound perception (thunderstorm/gentle rain) activated when there is an expected change in the environment (14pm and 17pm)	vibrotactile and auditory	awareness
	Changes in an unexpected state	The system detects an unexpected change in the environment (e.g. instead of the fog, it starts raining) and it informs the ATCO.	- Vibration~~/Long "beep"~~ and sound perception (thunderstorm/gentle rain) notify the unexpected changes - The kind and intensity of vibration and sound vary based on the impact of the unexpected changes on the operations (2 options: reduced or suspended operations)	Visual and vibrotactile and auditory	Enhance the information sharing, the situation awareness and the time reaction
Operate quickly and efficiently to solve an emergency	**Emergency situation**	The system informs the operator of the emergency	- Variation of the brightness intensity of the display with the airport interested by the emergency (T1) - The brightness increases if the ATCO has a low time-reaction (T2) - Additional display (or icon) movement (e.g. shaking, jumping) are activated when the ATCO does not take any decision for a long period of time (T3) - T1, T2 e T3 represent the	Visual, vibrotactile	of Improve the time-reaction and the situation awareness

			increase of the level of situation severity (growing intensity) - Vibration coming from the wearable bracelet		
Identify and recognise the airport requiring the operator's attention among the three environments	**Sound spazialisation**	- The main active frequency is the one of the primary airport - Those of the secondary ones are in a sort of standby - The system provides the operator with the sound of an incoming call. - The sound of the incoming call is reproduced in the right or left side of the headphones depending on which of the secondary airports it corresponds to. - The sound of the call is combined with a voice (e.g. high-low tone, woman/man voice) notifying the incoming call to the operator - In addition to this auditory info, also an icon appears at the top of the display notifying that someone is speaking (e.g. sound waves) - When the operator starts a new communication with a secondary airport, s/he has to rotate his head	- Auditory (sound of the incoming call) and visual (icon) inputs - Head movements toward the secondary airport interested by the call - Voice recognition: the icon moves together with the pilot's and controller's speech	Visual and Auditory	Increase the situation awareness and decrease the workload, as the spatialized sound+visual combination allows the operator to quickly identify the airport requiring his/her attention.

		and to speak directly looking at the specific secondary display. The system catches the head movement and a directional microphone catches the message. At the same time, an icon (the same of the previous point) follows his/her speech - If the system does not catch the message clearly, the color of the icon and its movement will change (e.g. red); while when the message is clear the icon will be colored differently (e.g. green).			

4.1.3 Step 3 – Concept development

During this phase the description of the micro-scenarios of Multiple Remote Tower control has been refined with the support of an Air Traffic Controller, who was required to provide a feedback on the coherency of the operational aspects and of the communications between the actors involved (e.g. Tower Air Traffic Controller and pilot) in the scenarios. In addition, once collected the ATCO's comments and suggestions, the proposed multimodal solutions for RTOs identified in the previous phases have been described in relation to the context (scenarios) of use defined thanks to the ATCO's involvement in this design step.

From a methodological point of view, the choice of developing micro-scenarios aimed to create a variety of specific brief situations, showing examples of how the multimodal interactions can take place and which tools and/or system functionalities can enable the interaction with the Controller Working Position.

Here below the multimodal interactions is reported in the form of graphic representations, immersed in the micro-scenarios finally developed with the support of the Air Traffic Controller, enriched by the description of the context and of the interactions modalities.

Need	**Solution**	**Event**	**Multimodal interaction**	**Enable technology**	**Expected benefit**
Monitor 3 airports during Multiple Remote Tower Operations	**Controller Working Position**	The ATCO is monitoring the runways and taxiways of three aerodromes in a configuration 1:3	Physical interaction	- Primary and secondary screens - Dashboard	Improvement of situation awareness about the flight traffic of each environment

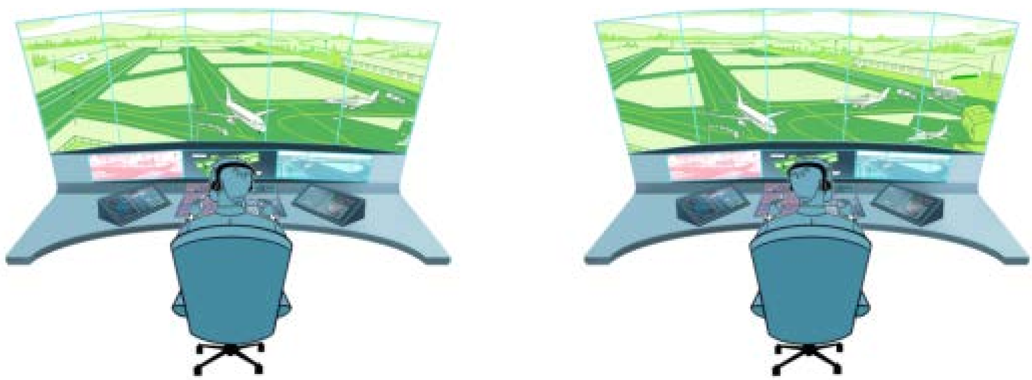


Figure 21 - CWP visualisation in the baseline setting

This Controller Working Position is divided in two spatial sections which represent different airports. Each airport is identified with a coloured coding (e.g. a coloured cover for each display); in the concepts reported below, the colour coding are green for the primary one, pink and blue for the secondary aerodromes. Here below are described the characteristics of each display.

1 - Primary screen: it is on the top in the foreground (green screen) and it shows the airport where the TWR ATCO is managing the aircraft movements in a specific period of time. The surface movement radar is visualised in the corresponding secondary screen.

2 - Secondary screens: they are placed at the bottom of the primary screen and they reproduce the remaining two airports that the TWR ATCO monitors in parallel to the primary one.

3 - Dashboards: each dashboard contains the flight progress strips and it can also be setting with other tools, like for example the air radar, the NOTAM and the weather information of the corresponding airport.

In addition, among the possible interaction modalities between the operator and the Controller Working Position there is the head rotation associated to an enlargement of the view, which enlarge the field of view reaching the 120 degrees.

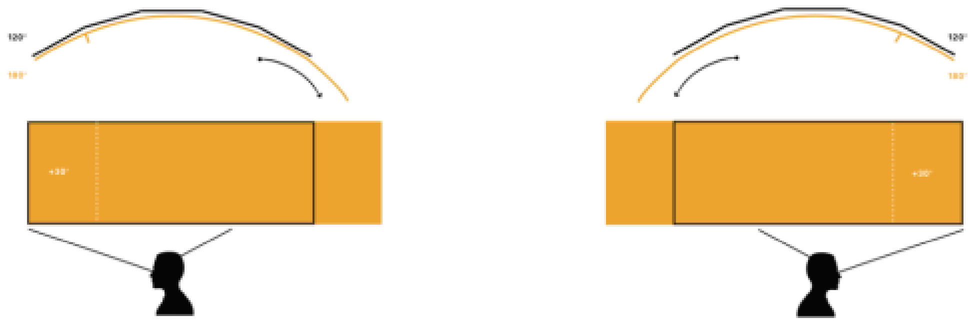


Figure 22 - Visualisation of the extended view until 120 degrees

Need	Solution	Event	Multimodal interaction	Enable technology	Expected benefit
Manage aircraft and vehicles moveme nts on more than 1 airport	**Transition between 3 airports**	The ATCO receives a request of clearance to land from a secondary aerodrome; s/he switches the visualisation from the primary aerodrome to the secondary one	Body interaction	Wearable bracelet(s)	Improvemen t of situation awareness and decrease of the workload with regard to the flight traffic of each environment

Figure 23 - The operator changing the primary visualisation

The interface gives the ATCO the possibility to always have at her/his disposal the environments to be controlled and to switch from one to another with an arm control movement (right/left side) when necessary.

The movement is also supported by two wearable bracelets which add precision to the recognition of the movements in the space around the operator.

Need	Solution	Event	Multimodal interaction	Enable technology	Expected benefit
Monitor the activities and check the runway status at secondary aerodromes	**Preview of a secondary airport**	During a period of inactivity at the primary aerodrome, the ATCO gives a look at the traffic at one of the secondary screens	Body interaction	Wearable bracelet(s)	Improvement of situation awareness with regard airport activities and runway status of a secondary environment

Figure 24 - The operator doing an overview of one of the secondary airport

When the visualization is on the primary aerodrome, the operator can do an overview of one of the secondary airports.

The interaction is executed with a gesture control movement of the arm; the operator with a drag and hold interaction can maintain the visualisation of the secondary screen on the primary one, as long as s/he needs to look at the secondary airport.

The airport goes back to the initial configuration when the operator moves the arm toward the secondary screen corresponding to the airport in the overview.
When the operator activates this function, that means when the operator is looking at the secondary environment overview, s/he is able to ear the environmental sounds (e.g. wind, rain, storm, engine sound, birds flying in the vicinity and etc.).
This solution allows the operator to have a quicker and more fluid interaction during the transition between the virtual environments, providing potential support in the decreasing of the time-reaction when it is necessary to move the attention from one airport to another.

In addition, another interaction modality has been designed, taking into consideration the feedback provided by the two Air Traffic Controllers after the workshop described in the previous chapter.

Figure 25 - The operator interacting with a touch version of the secondary screens

In this case, the operator instead of moving the visualisation of the secondary airport to the master one, s/he does an overview of the environment with a touch interaction that allows him/her to zooming-in/-out to check the status of specific area of the runway and of the surrounding zones.

Need	Solution	Event	Multimodal interaction	Enable technology	Expected benefit
Organize and manipulate the Flight Progress Strips (FPS)	**Interaction with flight strips**	An aircraft calls for the clearance to land. The ATCO, checks if the runway is clear and gives the clearance to land. At the same time, ATCO takes note of the aircraft position. Once the aircraft is not under the operator's responsibility, s/he removes the strips.	Body interaction	Touch dashboard	More easy and quick organisation of the flight strips.

Figure 26 - Baseline operator position when interacting with the flight progress strips

The operator interacts with an electronic strips bay, where s/he has all the strips of a specific airport at his/her disposal, based on the chronological order of movements.

The system allows the Tower ATCO to recognise which airport the strips refer to thanks to the colour of the background of the dashboard. In the figure above, the operator is managing the strips of the primary airport, which is recognised with the green colour in the background. In addition, on the FPS interactive weather information relative to each aerodrome are reported on a timeline located on the right side of the strips.

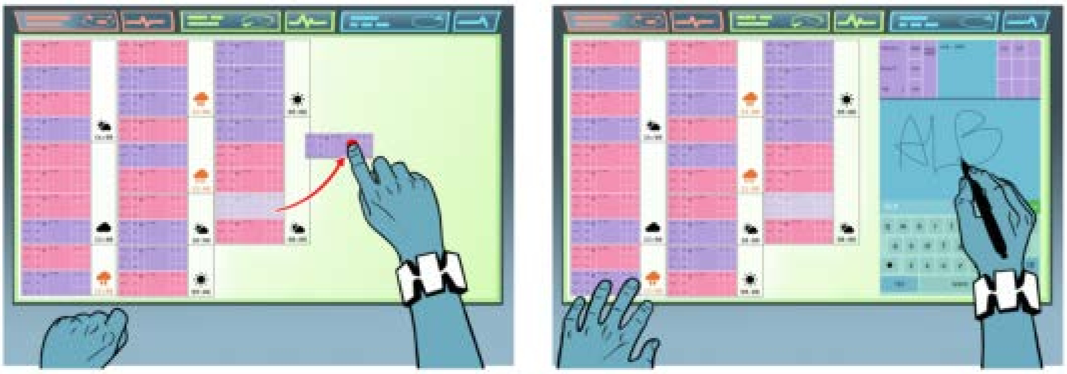


Figure 27 - The operator moving one of the strips to the right side of the dashboard to take notes

The system allows taking notes on the FPS using a tap on the display to select a specific strip and, moreover the operator can spread and pinch to zoom in and zoom out to the strip, in order to add more information.

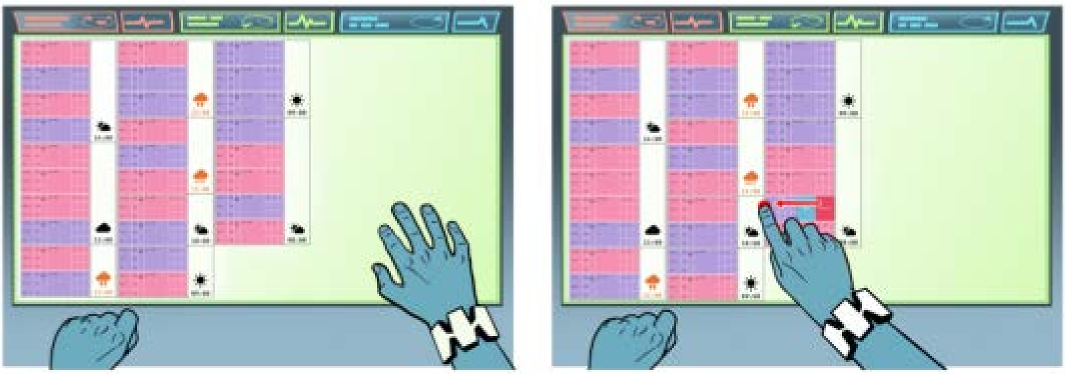


Figure 28 - The operator removes a strip from the strips bay

The FPS can be removed from the strip bay with a scroll movement when an aircraft is no longer under ATCO's responsibility.

Need	**Solution**	**Event**	**Multimodal interaction**	**Enable technology**	**Expected benefit**
Remember and check the runway status	**Voice recognition**	The ATCO receives a call from a ground vehicle of a secondary aerodrome asking for the authorisation to do an inspection of the runway. S/he approves the request and moves the secondary airport on the primary screen. While the inspection is in progress, from the other secondary airport, an aircraft calls requesting the clearance to take-off.	Body interaction	- Head tracking - Directional microphone - Display with overlaid information	Increase the situation awareness and decrease the possibility of error, due to the forgetfulness of the inspection in progress on the runway

Figure 29 - The operator interacting with the screen of the airport with the inspection

The voice recognition function allows the system to activate the “inspection modality” when the ATCO authorizes it through the radio frequency.

Figure 30 - Visualisation of the airport with the inspection on the primary screen

In the above figures, the inspection occurs in a secondary airport that the ATCO can move to the master screen in order to have a better control of the situation.

Figure 31 - Visualisation of the airport with the inspection when it is moved to the corresponding secondary screen

When the airport interested by the inspection is in the foreground, the ATCO can see the car on the runway. In addition, the system applies a coloured cover on the visualization of the airport with the inspection.

The coloured cover remains active on the airport display when it is moved to the bottom, as the figure above shows.

Figure 32 - ATCO interacting with a secondary airport through a touch interface

In addition, the operator has the possibility to zoom-in/out to the secondary airport in order to check the status of the inspection and to locate the ground vehicle monitoring the runway.

Need	Solution	Event	Multimodal interaction	Enable technology	Expected benefit
Check and communicate weather information	**Changes in an unexpected status**	The ATCO is visualising the primary airport where in 15 minutes is expected the next movement. An unexpected change of the weather conditions at the primary airport is detected and reported to the ATCO.	Visual, vibrotactile and auditory	- Display with overlaid information - Wearable bracelets - Headphones with environmental sound	Improve the situation awareness

Figure 33 - The ATCO checking the next movement at the primary airport

The operator has the weather information available on the timeline of the strips bar (e.g. an icon indicating a strong wind from 14pm to 17pm).

Figure 34 - The operator receives a vibration notifying that the weather info is changed

When an unexpected change in the environment is occurring (e.g. instead of a strong wind, it starts raining), a vibration from the wearable bracelet warns the operator.

Figure 35 - The operator receiving the different alerts on the unexpected change

At the same time, on the primary screen a visual alert reinforce the message and, as the ATCO is already listening to the environmental sound through the headphones, s/he perceives also the sound of the rain. Depending on the intensity of the phenomenon s/he decides if alerting the Approach sector in order to communicate to the pilot that the weather has changed and ask if s/he will land at that airport anyway.

Need	Solution	Event	Multimodal interaction	Enable technology	Expected benefit
Operate quickly and efficiently to solve an emergency	**Emergency notification**	The ATCO is visualising the primary airport where s/he had just ended to give the clearance to an aircraft. S/he receives a call from a pilot asking for an emergency landing at one of the secondary airport. The ATCO gives the instructions to the aircraft for the landing and s/he	Visual and vibrotactile	- Display with changing brightness - Wearable bracelets	Improve the time-reaction and the situation awareness

		communicates the type of emergency to the airport personnel.			

Figure 36 - The operator's attention is captured by the emergency at a secondary airport

The system informs the operator that there is an emergency at one of the secondary airports through a visual input, namely a change in the brightness intensity of the display of the airport interested by the emergency. The brightness intensity increases if the ATCO time of reaction is low and an additional moving icon is activated when the operator does not take any decision for a long period of time.

Figure 37 - A vibration in the wearable bracelets alerting the operator

If too much time passes before the operator's actions, also a vibration coming from the wearable bracelet is provided to the ATCO, in order to make him aware of the emergency in progress.

Need	**Solution**	**Event**	**Multimodal interaction**	**Enable technology**	**Expected benefit**
Identify and recognise the airport requiring the operator's attention among the three environments	**Sound spatialisation**	The ATCO receives a call from an aircraft of one of the secondary aerodromes, asking for the starting of the engine. The ATCO approves the request and gives the data for the starting engine. After 5 minutes, he also gives the clearance to take-off.	Body interaction	Wearable bracelet(s)	Increase the situation awareness and decrease the workload, as the spatialized sound+visual combination allows the operator to quickly identify the airport requiring his/her attention.

Figure 38 - Representation of the auditory information coming only from one of the headphones side

With regard to the communication of the operator with other actors of the working environment (e.g. the pilot), the principal active frequency is that of the primary airport, while those of the secondary ones are in standby.

When there is an incoming call, the system provides the operator with auditory information reproduced in the right or left side of the headphones depending on which of the secondary airports it corresponds to.

Figure 39 - The icon on the screen moves together with the speech of the operator

In addition to the auditory info, an icon appears at the top of the display notifying that someone is speaking (i.e. sound waves).

When the operator starts a new communication with a secondary airport, s/he has to rotate his head and to speak directly looking at the specific secondary display. The system catches the head movement and a directional microphone catches the message. At the same time, an icon (the same of the previous point) follows his/her speech.

Chapter 5

Conclusion

5.1 Summary of contribution

This thesis started with the study of a specific area of the Air Traffic Management (ATM) domain, namely the Remote Tower Operations (RTOs) and with the analysis of both the concepts of multisensory integration and of the embodied cognition. The reason behind the choice of the aviation domain comes from the interest in the way in which the work of Tower Air Traffic Controllers can be improved in the new and fertile concept of the RTOs, where the role and the responsibilities of the operators could change compared to the current ones, together with its operational modalities. The interest in the multimodal perception in everyday life was a starting point to explore its role in the aviation domain, a complex universe characterised by dynamic relations among the multiple ATM roles and systems. In addition, as the PhD has been carried out in a research and consultancy company (Deep Blue), working mainly in the aviation domain, there was the possibility to explore different aspects of this field from a Human Factors perspective, with the aim to analyse the performance of the actors involved in the complex ATM network (e.g. aircraft and helicopter pilots, Air Traffic Controllers, Safety Managers, Civil Aviation Authorities, etc.). In particular, the work carried out during the PhD aimed to study the role of the multimodal perception in ATM, in order to answer to the following research questions:

1 Is there any impact of multisensory integration on ATCOs' performance in control tower operations?
   1.1 If yes, what kind of impact is there, specifically with regard to situation awareness and workload?
   1.2 What kind of suggestions for the design of multimodal solutions can be provided to support ATCOs' performance in Remote Tower Operations?

The study of the literature on the RTOs highlighted that the main change the introduction of the Remote Tower Operations concept will consists in the transition between the Out-The-Window view to a visualisation mediated by High-Definition cameras and sensors able to provide information on the working environment (e.g. aircraft call-sign, speed, obstacles on the runway) especially stimulating the visual sensory channel. Next to the implementation of HD cameras, in the description of the new operational concepts, also tools to be introduced as support systems able to reproduce the environmental sounds are taken into consideration (see Chapter 3) but they are less explored and defined. At the same time, with regard to vibrotactile perception and body interaction, there are not indications on their potential use in the Remote Controller Working Position and during the execution of the Tower Control tasks in future RTOs scenarios. In the transition between the traditional Tower Control to the Remote environment, it was challenging to study how the human performance can be supported in order to maintain acceptable level of situation awareness and workload.

With regard to the multisensory integration and the embodied cognition, it was fundamental to study the way human beings perceive the world and how the body perception guides the human actions to achieve a scope during every day experiences in the surrounding environment.

The methodology applied for the development of the concepts was the co-evolutionary design approach, which gave the opportunity to gather inputs and feedback on technologies already in use and on evocative ideas originating from multiple domains, in addition to the aviation one. The process comprehended three phases: i) Problem Setting, ii) Concept Generation and iii) Concept Development. In each step various activities have been carried out, contributing to add pieces of a puzzle that brought to the development of the final set of concepts immersed in the context of application, the Remote Tower Operations where 1 Air Traffic Controller manage three airports.

The three phases were characterised by the exchange of multidisciplinary knowledge and expertise, which enriched the discussion among Human Factors

experts, Air Traffic Controllers and visual designers involved in the Concept generation phase. The Human Factors experts provided inputs on the refinement of the methodology to be used for the concepts design and on the most relevant human performance factors of the ATM domain to take into consideration for an efficient and reliable design. On the other side, the Air Traffic Controllers gave feedback on the operational aspects of the scenarios created for the concepts design process, with a special attention on the sequence of tasks usually performed by the operators. At the same time the visual designers shared their knowledge on different proposals of visual representations of the multimodal interactions, providing examples of both existing technologies and potential future interaction modalities for a multisensory context of RTOs. In order to answer to the first two questions ("*1) Is there any impact of multisensory integration on ATCOs' performance in control tower operations?; 1.1) If yes, what kind of impact is there, specifically with regard to situation awareness and workload?*"), in the first phase of the design process, the problem setting, the activity on the experimental exercise has been developed and performed. The exercise was an attempt to assess the role of the visual, auditory and vibrotactile stimuli integration during the execution of the Tower Control tasks. In order to do that, as already explained, the definition of the Tower Control scenarios with ATM experts was essential to analyse the main operational characteristics of the tower environment, especially of the TWR ATCO's tasks and of the tools used. The experts' feedback was collected during iterative meeting (i.e. interviews and workshops) and it contributed decisively to increase the level of ATM scenarios contextual realism in view of the execution of the experimental exercise with (Tower) Air Traffic Controllers. In addition, the review of the SA and workload measurement techniques was used as a basis to decide how to measure these HF concepts during the experimental activity.
The exercise was carried out to analyse the impact of the different sensory modalities, provided both in isolation (i.e. visual input) and in combination (i.e.

visual + auditory, visual + vibrotactile and visual + auditory + vibrotactile) during the 8 runs. Each participant had to perform the scenarios in two levels of complexity (Easy and Hard) and each run lasted around 5/6 minutes.

The data obtained with the experimental activity showed that the combination of three different modalities could improve the situation awareness and workload of the subjects; in fact the results demonstrated that there is a trend toward a preference of a combination between the Visual+Auditory and Visual+Vibrotactile modalities, especially for the scenarios with a high level of difficulty.

There is only one case in which the three modalities (Visual + Auditory + Vibrotactile) show a higher value than one of the preferred combination (Visual +Vibrotactile) and it refers to the result of workload and to the evaluation of the overall SA by the subjects (Figure 13) in the scenarios with a lower level of difficulty. As explained in Chapter 4, this could depend on the fact that while controlling a low volume of traffic, the three modalities can better support the operator in maintaining a low level of workload and to be prepared to the subsequent tasks.

The preparation and the execution of this activity were very demanding and some difficulties have been encountered during the planning phase. In regard to the purpose of this thesis, the element that contributed to slow down the experimental exercise was the difficulty in recruiting Tower Air Traffic Controllers to be involved in the exercise. This difficulty was probably related to the length of the whole test (requesting around 2.30/3 hours for each participant) and to the starting date of the exercise that was envisaged for the beginning of July but was postponed to the end of August. This delay did not allow to collect more than 12 subjects' data for the analysis reported in this thesis and to perform more accurate and specific statistical investigation; for this reason, the results presented in the chapter represent more a tendency than fixed evidence.

The final exploratory concepts are the results of a challenging and stimulating path which starting from the research questions, passed through the study of the aviation and multisensory integration concept, then it dealt also with the identification and definition of the scenarios of current Tower Operations, to reach the experimental exercise and finally it focused on the concepts design.

The trends about the multimodal interaction impact were used as one of the main input of the exploratory design, especially in relation to the role that multimodality has on the ATCO's situation awareness, workload and performance. In fact, based on the experimental exercise results and on the information gathered with the interviews, the workshops and the desk research, it was possible to suggest the more efficient configuration of i) interface functionalities, ii) interaction modality and iii) sensory channel that can better support the TWR ATCOs during Remote Tower Operations (see 3.1).

The second phases of the design process were more focused on the third research question: *1.2) What kind of suggestions for the design of multimodal solutions can be provided to support ATCOs' performance in Remote Tower Operations?*; in particular during the concept generation and the concept development steps, the interviews, the focus groups and the workshops had the objective to identify suggestions on which sensory modalities, both in isolation and in combination, could better support the ATCO's tasks in Remote Tower Operations. The final exploratory design brought to the development of a set of multimodal interactions that has been reported in the form of graphic representations, immersed in the micro-scenarios developed with the support of the Air Traffic Controller, enriched by the description of the context and of the interactions modalities.

The multimodal interactions and the solutions identified at the end of the design process (see 3.1) can be considered as the final output of the work performed in this thesis and as the answer to the last research questions. They have been chosen as the most suitable suggestions for the design of multimodal concepts in RTOs scenarios; they do not pretend to be final results but initial inputs for who might want to explore the stimulating and fertile field of multimodality with regard to the emerging Remote Tower Operations research domain.

This thesis gave the possibility to explore and look closely to the ATM world in multiple occasions, as during observations at the Tower Control environment and when carrying out the interviews and the focus group with ATCOs for the scenario phase and with the participation in the experimental exercise. In those occasions, the knowledge on the ATCO working environment and on the operational aspects improved compared to the experience had before the starting of the three-year work; these experiences contributed to the acquisition and to the adoption of a more informed perspective on the Tower control procedures, especially when designing the multimodal concepts for RTOs.

Moreover, the work on the measurement techniques used in the experimental exercise to assess the Human Performance (i.e. situation awareness and workload) gave the opportunity to enrich the personal know-how on the more appropriate techniques to choose with respect to the context under analysis.

The design activity improved the theoretical knowledge and the practical skills in carrying out all the phases of the design and in selecting the more accurate methodology to apply when developing user-centred solutions, in order to be able to include all the relevant aspects of a complex network, as that of the ATM system.

5.2 Directions for future work

The development of an experimental exercise turned out to be a valid method to test the impact of the multisensory integration on Human Performance aspects, as situation awareness and perceived mental workload and/or additional ones, as stress and fatigue of the (Tower) Air Traffic Control operators and capacity and safety of the operations. Starting from the complexity conditions and the multisensory modalities combination, the experimental exercise could be adapted to other operational context, both in the ATM domain and in other fields where this kind of test could contribute to explore the relation between embodied cognition and the interaction within the surrounding world. Concerning the ATM domain, the exercise could be designed also for other kinds of remote operations, as for example those performed with the Remotely Piloted Aircraft Systems (RPAS), commonly known as drones. In this case, the study of the multisensory combination could support the drone’s pilots to improve the safety and the situation awareness related to the environment they are operating in, and to decrease the workload, especially in case of emergency situations due for example to the loss of control of the vehicle.

Concerning the concepts design activity, the final results will be taken into consideration for the purposes of the MOTO project, as a starting point to explore additional technological solutions and/or new RTOs scenarios to be implemented in a Virtual and/or Augmented Reality platform in order to assess their validity during new experimental exercises. When designing technological solutions to be introduced in a new and young operational environment, as that of the Remote Tower Operations, it would be appropriate to involve the end-users in the process of design, in order to collect their needs and feedback, in particular on the impact that the multimodal interactions could have on their performance and working processes. The work done with the concepts design could be considered as an initial step into the path that leads to the development of multimodal interaction modalities, enabled by tools and systems, which took into consideration from one side the technological progress and the international research advances in the RTOs context, and from the other side the analysis of the potentialities and limitations of these solutions in supporting the Tower ATCOs performance, in order to introduce useful, acceptable and reliable interactions with the working environment.

Appendix A

MOTO Interview to ATCOs - Template

MOTO – ATCOs Interview

The following interview has been developed to collect information on the current tower operations, in order to finalise a set of baseline scenarios in which the embodiment cognition can have a useful role in improving ATCOs performance.

<u>Introduction:</u>

MOTO (the embodied reMOte Tower) is a Horizon 2020 project in the framework of the SESAR Research and Innovation Action (RIA). It started in June 2016 and will have the duration of 24 months.

The main objective of the project is to identify the key multimodal stimuli required on Remote Tower platforms to enhance the sense of Presence experienced by ATCOs.

MOTO is expected to deliver ways to enhance the sense of Presence in Remote Tower Air Traffic Controllers in order to improve the attention levels, the decision-making process and facilitate real-world knowledge and skills transfer to a simulated worksite (Remote tower context). A secondary benefit that is expected is the development of brain-physiological indexes, customized for Remote Tower operations.

The project puts together four qualified partners representing SME, academia and research institutions: Deep Blue, Sapienza University of Rome, University of

Groningen and ENAC.

Questions:

The ATCO contribution is fundamental to explore the role of the embodiment and of the human body perception in the current Tower (TWR) operations. The information, provided during this interview, will be used to finalise the requirements for the definitions of a set of scenarios, which is the first step of a process that will lead to the reproduction of realistic tower scenarios in a virtual environment.

(1) Do you have any experience with and/or in Remote Tower Control?

(2) In your opinion, which are the similarities and differences between "out of the window" operations and Remote Tower operations?

(3) Do you think that the job of the ATCo will change from current operations to remote ones? In which way? Could you please make some examples?

(4) In regard to the current "out of the window" operations, could you describe which information you receive through the visual channel and which one through other sensory channels (e.g. audio channel, vibro-tactile perception, etc.)?

  (a) (If the ATCo answers the question (4) with examples): Could you please describe one or more examples of operational situations in which you receive the above-mentioned information?

  (b) (If the ATCo does not answer the question (4) with examples): Imagine one or more operational situations like, for example:

   - Good/Bad visibility;
   - Taxing/landing/departure;
   - Movement on ground.

Which kind of information do you receive during the different contexts and in which way?

(5) In your opinion during bad visibility situations, are the vibrations and/or the auditory information relevant and useful to understand the situation and to perform the tasks you are responsible of? If yes, in which way and in which situation?

(6) Which are the phases of flight during which the ATCo could make more use of the information provided through the audio channel or through the vibrations (e.g. departure, landing, taxing, etc.) or other sensory channels? How the information provided could be useful? To understand what? (e.g Landing gear set – landing; vehicles movement on ground- Taxi).

(7) The data collected during the literary review highlighted some ATCOs comments related to the importance of the multisensory integration during the Tower Control. What is your opinion about this? Do you think that the multisensory integration could be useful in your job? How?

Appendix B

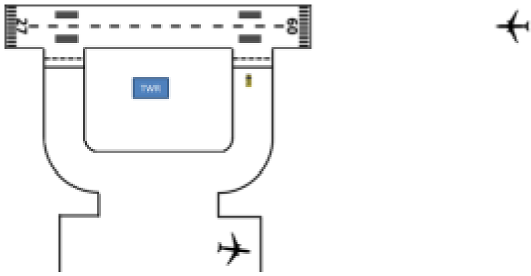
Preliminary operational scenarios of control tower operations

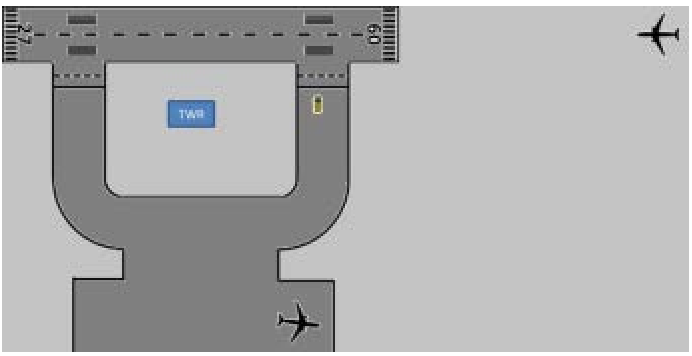
A dedicate template has been created for the scenarios and for each of them the following information has been provided:

- o Operational setup: brief sentence that describes the operation;
- o Visibility conditions: day/night, good/bad visibility;
- o Nominal/non-nominal condition;
- o Flight phase;
- o Context: information on the tower location, together with the traffic conditions and in some cases of the application of standard procedures;
- o Type of tasks performed: chronology of the ATCO tasks performed during the scenario;
- o Scenario sketch;
- o Scenario description: detailed explanation of the different steps characterising the scenario.

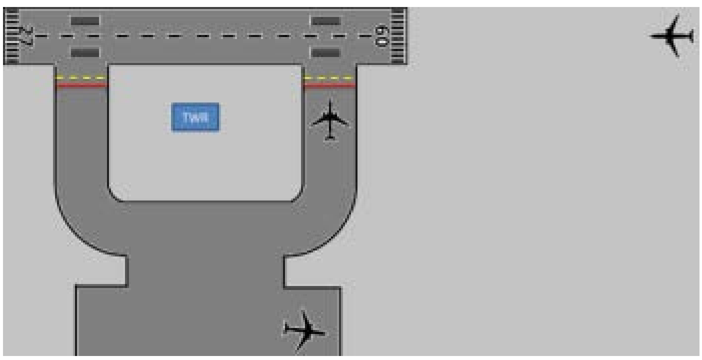
Here below the scenarios with the relative templates, called *Scenarios Cards*, are reported:

Scenario 001a: Runway inspection	
Operational setup	One TWR ATCO provides ATS to a single remotely operated airport
Visibility conditions	Daylight/CAVOK
Nominal/Non nominal	Nominal traffic coordination
Flight phase	Landing/Taxi-out/ Take-off
Context	Remote TWR ATCO is located in a RTM away from the controlled airport. Controlled airport with a single runway.
Type of tasks performed	- Communication with “follow-me”

	- Landing clearance - Start-up and push-back clearance - Take-off clearance
Scenario sketch	
Scenario Description	
The scenario describes nominal operations at the remote controlled aerodrome during day operations. Meteorological conditions are good (CAVOK). It is 16:30 local time and ATCO's shift initiated 1.5h ago. There is an aircraft approaching the airport while there is another that is waiting for the pushback. At the same time there is a ground vehicle that asks for permission to perform a runway inspection. The ATCO should decide to give clearance to the runway inspection vehicle or if he should postpone it after the aircraft lands or after the other aircraft takes-off.	

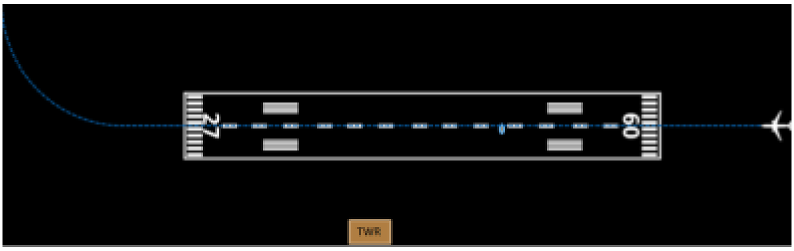
Scenario 001b: Runway inspection + LVP	
Operational setup	One TWR ATCO provides ATS to a single remotely operated airport
Visibility conditions	Daylight/Low visibility conditions /Cat II
Nominal/Non nominal	Nominal traffic coordination
Flight phase	Landing/Taxi-out/ Take-off
Context	Remote TWR ATCO is located in a RTM away from the airport being controlled LVP procedures are applied. Controlled airport with a single runway.
Type of tasks performed	- Meteorological Observation - Runway inspection - Landing clearance - Start-up and push-back clearance - Take-off clearance
Scenario sketch	
Description	
The following scenario describes nominal traffic coordination with Low Visibility conditions at the remotely controlled airport during day operations. The ATCO realizes there is a degradation of the meteorological conditions on the airport being remotely controlled with the support of Automated Weather Observing System (AWOS) and Auto-Meteorological Aviation Report (METAR) and initiates LVP operations due to foggy conditions and some rain.	

The ATCO is coming from a period where he was slightly under loaded (with less movements). There is an aircraft approaching the airport while there is another that is waiting for the pushback. At the same time there is a ground vehicle that asks for permission to perform a runway inspection. The ATCO should decide to give clearance to the runway inspection vehicle or if he should postpone it after the aircraft lands or after the other aircraft takes-off.

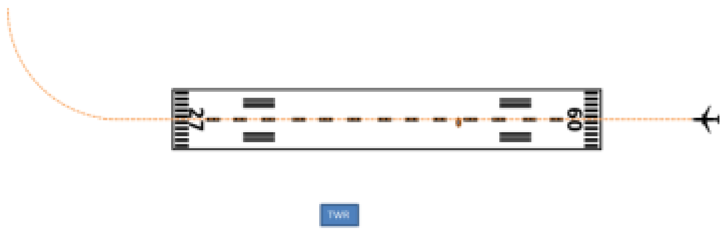
Scenario 002: Heavy fog	
Operational setup	One TWR ATCO provides ATS to a single remotely operated airport
Visibility conditions	Daylight/Low visibility conditions /Cat II
Nominal/Non nominal	Nominal traffic coordination
Flight phase	Departure and Arrival /final approach
Context	Remote TWR ATCO is located in a RTM away from the controlled airport. LVP procedures are applied. Controlled airport with a single runway. High traffic density
Type of tasks performed	- Meteorological Observation - Landing clearance - Line-up clearance
Scenario sketch	

Scenario Description
It is 7 a.m. and there is heavy fog at the airport. The ATCO cannot see either end of the runway and is controlling the traffic by the low visibility rules. The stop bars are activated. One aircraft is on final and another aircraft is waiting on a holding point for the departure. The controller has given the incoming aircraft a landing authorization and is waiting for the pilot to report when it has vacated the runway. When the controller receives the report, he/she can give the line-up authorization (i.e. clearance) for the holding aircraft and turn off the stop bar lights.

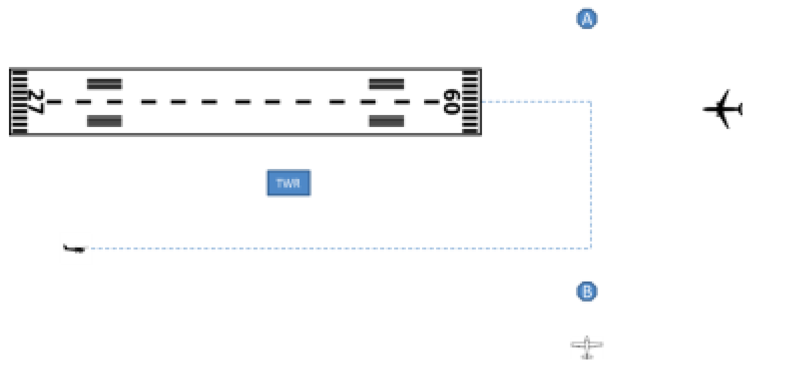
Scenario 003a: Obstacle on the RWY _NIGHT	
Operational setup	One ATCO provides ATS to a single remote airport. The Remote TWR ATCO is located in an RTM away from the aerodrome and/or local Tower. Both the Remote TWR ATCO and the aerodrome are located in a region of the Central Italy.
Visibility conditions	Night shift/Good visibility conditions
Nominal/Non nominal	Non-Nominal traffic coordination
Flight phase	Final approach /Landing
Context	Airport
Type of tasks performed	- Landing clearance - Verification of obstacle on the runway - Communication with ground personnel - Clearance of go-around - Clearance of landing

Scenario sketch	
Description	
The scenario describes an aircraft final approach to the remote controlled aerodrome during night operations. The ATCO, while giving clearance to the pilot, notices the presence of an obstacle on the runway. The ATCO contacts the ground personnel to remove the obstacle but he experiences difficulties in the communication with them. There is not enough time for the aircraft to land, therefore, the ATCO gives clearance to the pilot to perform a go-around.	

Scenario 003b: Obstacle on the RWY	
Operational setup	One ATCO provides ATS to a single remote airport. The Remote TWR ATCO is located in an RTM away from the aerodrome and/or local Tower. Both the Remote TWR ATCO and the aerodrome are located in a region of the Central Italy.
Visibility conditions	Daylight /Good visibility conditions
Nominal/Non nominal	Non-Nominal traffic coordination
Flight phase	Final approach /Landing
Context	Airport
Type of tasks performed	- Landing clearance - Verification of obstacle on the runway - Communication with ground personnel - Clearance of go-around - Clearance of landing

Scenario sketch	
Description	
The scenario describes an aircraft final approach to the remote controlled aerodrome during daylight operations. The ATCO, while giving clearance to the pilot, notices the presence of an obstacle on the runway. The ATCO contacts the ground personnel to remove the obstacle but he experiences difficulties in the communication with them. There is not enough time for the aircraft to land, therefore, the ATCO gives clearance to the pilot to perform a go-around.	

Scenario 004: No visual contact	
Operational setup	One TWR ATCO provides ATS to a single remotely operated airport
Visibility conditions	Daylight/CAVOK
Nominal/Non nominal	Nominal traffic coordination
Flight phase	Departure and Arrival /Landing
Context	Remote TWR ATCO is located in a RTM away from the controlled airport. Controlled airport with a single runway. High traffic density
Type of tasks performed	- Plan landing coordination - Authorise IFR landing - Authorise VFR landing - VRP coordination

<table>
<tr><td>Scenario sketch</td><td>
</td></tr>
<tr><td colspan="2">Scenario Description</td></tr>
<tr><td colspan="2">It is 2 p.m., there are several small (e.g. VFR) and large (e.g. IFR) aircraft in the airspace. IFR flight is on final approach while a VFR flight is required to report the VRP (B and A in the sketch). Although the controller knows the approximate position of the VFR aircraft, he/she is unable to obtain visual contact because there is other traffic at the same direction. ATCO could decide if VFR a/c can safely fly from B to A or remain on holding on VRP B.</td></tr>
</table>

Appendix C

Review of Task Analysis techniques

The Task Analysis (TA) can be defined as the analysis of the task that an individual performs during and through the use of a technological system. This type of analysis examines the whole man-machine system, focusing on the way in which a task is performed, including the duration and complexity of the task, the activities (physical and cognitive) carried out by an operator, the environmental context in which the human-machine system is inserted and other elements (if any) that allow the operator to carry out the task effectively.

Among the first TA theorists, we find Diaper and Stanton who define the TA as "Task analysis is the collective noun used in the field of ergonomics, which includes HCI, for all the methods of collecting, classifying, and interpreting data on the performance of systems that include at least one person as a system component" (Diaper and Stanton 2003: 14). From the definition of Diaper, it is clear that the central elements of the Task Analysis concept are the way in which a system "behaves" over time, the information that can be gathered from the various components of the system and their relationships during a time frame. Moreover, Pylyshyn and Bannon affirm that "Task analysis involves establishing who the users are, what their goals are in performing the task, what information they use in performing it, what information they generate, and what methods they employ" (1989: 264).

According to Di Nocera, whatever the perspective adopted, at the centre of the TA there are a description of the world and an account of how a work is performed in the described world (Di Nocera 2011). The first element differentiates TA from laboratory studies; while the second aspect makes this analysis different from other strictly observational approaches.

The purpose of the TA is to identify methods and techniques to ensure that system requirements are met and to identify the reasons that hinder the fulfilment of a specific operational configuration. The different techniques of task analysis “are targeted to capture different level of granularity and focussing on different aspects of the tasks execution” (Tavanti and Bourgois 2006: 3); to achieve this goal, they usually include a phase of breaking down the operator's activity into sub-units.

Usually the methods of existing task analysis date back to the early twentieth century with the Scientific Management movement and the studies of Frank and Lilian Gilbreth, together with those by Frederick Taylor. Through the observation of the multiple ways of executing a task, the formers tried to identify the fastest and most effective sequence to perform it and to do so, they adopted the technique of the task division into its individual main components. Taylor is responsible for the application of scientific rigor to the study of the tasks performance in a work context. The scholar posed a series of questions about the way a task is performed; the elements or actions necessary to execute it; the reasons behind the methods of carrying out the task; the solutions to improve the working methods. Taylor's work “inspired the development of methods to formally describe human performance, in order to increase the quantity and the quality of the work carried out” (Tavanti and Bourgois 2006: 3). In particular, the decomposition of the task in sub-units and the critical method of Taylor have influenced the development of modern task analysis techniques, which also examine the study of how a task is performed in reality and what could go wrong in the execution, in addition to the analysis of how a task should be performed as theorised by Taylor.

As far as the task analysis methods are concerned, there are different types of TA and in order to identify the best technique for a specific purpose, Diaper and Stanton (2003) recommends asking the following questions:

- What do you want to analyse with the task analysis?
- What kind of format is most appropriate to represent the results of

the task analysis?

- What types of data can be collected?
- Which task analysis method / method is most suitable / effective for converting data into an effective representation for its own purposes?

The techniques of task analysis can vary a lot between them and for this reason this analysis tool can be adopted in different fields and with equally different objectives. Although there are different types of TA, Diaper and Stanton (2003) have identified the following three elements in common to all the techniques:

- The goal of the TA is always to solve problems;
- All TA techniques refer to performance;
- The level of analysis must be as simple as possible.

Furthermore, each analysis consists of a phase of data collection and representation, followed by the creation of the list of activities and, finally, the analysis itself.

Below are some TA techniques that highlight how the analysis methodology can vary based on the purpose of the research to perform.

Task-Cantered System Design

Task-Cantered System Design is a technique developed in 1993 by Lewin and Rieman with the aim of creating prototypes of interfaces; this method is inspired by the discount usability and consists of four steps:

1. Identification of the users of a system: it consists in the identification of the tasks performed by the operator during the interaction with it and the reasons behind the actions performed. In order to carry out this phase effectively, it is advisable to involve expert end-users in the evaluation of the task description, of the system and of the interaction under analysis;

2. Identification and analysis of the user's needs as part of the target user: in this phase, it is necessary to choose which tasks to analyse and which ones to leave outside the scope of the research;

3. Development of a design scenario that describes in detail the user, the context in which the task is performed and the tools with which s/he interacts to complete the task;

4. Evaluation of the task through the use of the walkthrough technique: this step envisages that a system user, preferably, performs a precise task using the interface under development, providing h/his opinion on the interface and on the interaction process. The interview technique can be a valid tool to carry out this phase of the analysis.

The greatest criticality that has been identified for this method is the lack of precision, especially with regard to high critical work environments. Despite that, this technique is characterized by being an easy to use model when analysing the potentialities and the limitations both of a system and of its interaction with the operator.

Cognitive Task Analysis (CTA)

The goal of this technique is to identify the cognitive skills and effort which are necessary for the operator to perform a task efficiently. Cognitive Task Analysis (CTA) is an approach that differs from the mere observation of an individual's activity, as it complements the traditional description of a task with the study of the operator’s implicit knowledge. The implicit knowledge can be influenced by both the individual expertise and experience. For this reason, it can be said that “CTA covers a range of approaches used for looking at mental (hence cognitive) internal events or knowledge structures” (Kirwan and Ainsworth 1992: 402).

This method can be used in different fields as mental abilities are increasingly involved in today's work environments. The most used tool to collect data in this case is the in-depth interview with expert users of the systems under analysis; this technique aims to analyse the cognitive strategies of assessment and interpretation of the situation that an individual puts in place during his/her work performance. The interviews are usually integrated by the analysis of tasks and sub-tasks, whose descriptions is produced by observations of the real operational context and by further interviews with users.

The critical point of this method is its high specialization that may be of little use for the designers who need to collect data for the development and evaluation of a new interface. In addition, "As a matter of fact, knowledge elicitation demands a very good level of understanding of the domain studied. Moreover CTA does not provide a shared set of methods to represent the knowledge domain in a systematic manner" (Tavanti and Bourgois 2006: 15). To overcome this limitation, within the Navy Personnel Research and Development Center project some researchers like Militiello and Hutton (1998) have developed a simplified version of the CTA: the Applied CTA (ACTA). The goal of this new version is to provide designers with useful design recommendations resulting from the collected data on the cognitive abilities involved during the task performance in highly complex environments.

ACTA foresees a first phase of decomposition of a task in its relative sub-tasks; then an assessment of users' knowledge is made, dividing them between novices and experts to identify which skills are required to execute a task and which mistakes are made by both novices and experts. As Di Nocera points out, the research is directed in specific ways on those categories that seem to characterize the expertise, such as diagnosis and prediction, awareness of the situation, perceptual abilities, improvisation and so on, with the clear intent to discover the nature of these abilities and the particular events in which they are called in play (Di Nocera 2011). The third phase consists of interviews built on simulation scenarios that describe the tasks performed in a specific operational context. The data obtained are then used by the designers to choose and/or modify specific elements of the system under development.

Hierarchical Task Analysis HTA

The Hierarchical Task Analysis (HTA) is a technique that allows to analyse complex tasks by breaking them down into sub-tasks and operations based on a hierarchical sequence, whose central unit is the operation (also called “action”) and which is usually represented with graphs and tables. More specifically, HTA is a task analysis technique that identifies the following elements for each task:

- Objective and related sub-objectives;
- Operations: they represent the individual actions and used to achieve the objectives;
- Plans: they include the choices and operations implemented by the subject and, furthermore, they define the activating conditions that allow one or more objectives to be met.

These elements are identified and analysed with a series of steps that together with the analyst's experience allow to carry out an effective analysis of the task:

1. Identify the objective of the analysis;
2. Search and access different types of information on the system and on the context to be analysed, such as field observation, interviews and briefing with domain experts, design of simulation scenarios;
3. Identify the objectives and sub-objectives of the system, together with the techniques and the strategies put in place to achieve a specific goal. The latter is decomposed into operations and for each of them the related sub-objectives are identified;
4. Linking the objectives and sub-objectives, identifying through the plans the conditions that activate each sub-objective. The plans identify the context in which these sub-objectives are lowered and it must be defined from a temporal, environmental and structural point of view, considering the information present in it;

5. Representing the hierarchy of the system through the use of a table or a diagram. Each of these two types of representation has advantages, and they are often adopted together to allow a more immediate understanding of the results obtained;
6. End the analysis when it is consistent with the original objective. To do this, the following formula is used: PxC rule and if the analyst evaluates the result as acceptable, then the process can be interrupted. This phase is considered one of the most difficult, as the choice of when to stop the analysis depends a lot on the experience of the scholar;
7. Analyse again the decomposition of the objective into sub-objectives, using the support of expert users of the system;
8. Revisit and modify the analysis, if necessary: this step depends on several factors, such as the length and complexity of the task under analysis, as well as the time that the analyst has available to perform it.

The Hierarchical Task Analysis is used in many fields of study, including: i) the analysis of human-machine interaction; ii) the design of an interface; iii) the development and evaluation of operating procedures; iv) the study and evaluation of errors during the task performance; v) the analysis of the workload.

A positive aspect of this method lies in the fact that it allows the analyst to describe a task in detail, thanks to its hierarchical subdivision; it gives also the possibility to identify what needs to be done to achieve a goal and it can be used as input for other types of analysis, such as workload assessment and error analysis (Callan et al., 2005).

On the other hand, however, in order to obtain valid and reliable results, a lot of practice and time is required to the analyst to efficiently use the HTA; furthermore "it can be ambiguously deployed, i.e. different notations and terminologies can be used to structure the charts; in-depth analyses of complex activities could be difficult since they require an extensive hierarchical charting" (Tavanti and

Bourgois 2006: 14). Another critical point is that this approach focuses primarily on the functioning of the system, rather than on the user; in fact "HTA provides effective means of how the work should be organized in order to meet a system's goals. Thus the activities of the human operator are linked directly to the requirements of the system" (Kirwan & Ainsworth, 1992: 102).

MUSE

The Method for Usability Engineering (MUSE) is a task analysis technique that aims to support and improve the new systems design in the airport control towers domain, with a special attention on the analysis of the system requirements and specifications. This method attempts to face some task analysis limitations, as for examples "the requirement for an existing system, the focus on analysis rather than design, the limited scope of application in the design cycle, the under specification of the application domain, the inadequate documentation of outputs, the little guidance in the selection of a particular method" (Marti 1998: 1664).

The main phases of MUSE are reported here below:

1. Information elicitation and analysis: this step is composed of an initial system analysis during which information related to tools in use and to those involving similar tasks is collected; and of a development of a task models independent from the system currently in use, the Generalised Task Model (GM);
2. Design synthesis: during this phase the human factors requirements for the design are collected and described in the form of user's needs statements; once finalised the requirements, the Composite Task Model (CTM) is created, it includes the tasks related to the system, to the users or to both of them and it also expresses the functionalities of the system to be developed;
3. Design specification: it is divided into two steps, the first one is the interaction task model and it consists in the identification of those actions that the user performs using the device and the characteristics of the display objects; the second one, the display design phase, "provides a set of pictorial screen layouts

corresponding to the specification provided by the interaction model" (Marti 1998: 1665).

The benefits of this method are the possibility to model single agent tasks and its flexibility, in fact it can be used by both designers and analysts in multiple application fields. Nevertheless, in order to efficiently apply this method, training and experience are necessary; moreover MUSE does not provide sufficient instruments for the communication and collaboration among other actors of air traffic control scenarios. In this regard Tavanti and Bourgois state "MUSE takes the individual as the main unit of analysis, thus discarding the implications deriving from adopting a distributed, socio-technical framework" (2006: 4).

Appendix D

Measurement Techniques for the experimental exercise

In this Appendix, the questionnaires used to measure SA, workload and performance (SME questionnaire) are reported as supplementary worksheets for the experimental exercise reported in Chapter 4.

Situation Awareness questionnaire

The technique identified to measure the Situation Awareness (SA) was a well-consolidated subjective measurement technique created by EUROCONTROL in the framework of the SHAPE (Solutions for Human-Automation Partnerships in European Air Traffic Management) programme.

The subjects have been briefed at the start of the experimental trials, as suggested by the EUROCONTROL guidelines of the SASHA_Q implementation.

Here below it is reported the SASHA questionnaire that has been used during the experimental exercise.

Table 14 - Situation Awareness questionnaire

SITUATION AWARENESS						
	Never	**Seldom**	**Often**	**More often**	**Very Often**	**Always**
I was ahead of the traffic	0	1	2	3	4	5
I started to focus on a single problem or a specific area of the sector	0	1	2	3	4	5
There was a risk of forgetting something important (like transferring an a/c on time or communicating a change to an adjacent sector)	0	1	2	3	4	5
I was able to plan and organize my work as I wanted	0	1	2	3	4	5

I was surprised by an event I did not expect	0	1	2	3	4	5
I had to search for an item of information	0	1	2	3	4	5
How would you rate your overall SA during the run?	1 2 3 4 5 6 7 8 9 10 Very Poor Very Good					
Explain what factors contributed for your lack of SA:						

Subject Matter Expert

The Subject Matter Expert evaluation had the aim to assess the subjects' performance after each run. The SME questionnaire (see Table 6) consisted in three questions dealing with the overall performance, situation awareness and workload of the subjects and for each question, the SME had to provide a rate from 0 (Very Low) to 10 (Very High).

The results of the SME evaluation have been compared to the results of the SA and workload questionnaires in order to study any possible relation and to enrich the pool of data.

Table 15 - SME evaluation questionnaire

SUBJECT MATTER EXPERT EVALUATION	
Overall Performance during the run	1 2 3 4 5 6 7 8 9 10 Very Low Very High
Overall Workload during the run	1 2 3 4 5 6 7 8 9 10 Very Low Very High
Overall Situation Awareness during the run	1 2 3 4 5 6 7 8 9 10 Very Low Very High

Perceived Cognitive Workload

With regard to the measurement of the workload, after each run the ATCOs filled in the NASA-TLX questionnaire (see Table 7), a standardized multidimensional assessment technique that rates the level of workload perceived by a subject and which uses six dimensions to assess the perceived cognitive workload:

1. Mental demand: How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?
2. Physical demand: How much physical activity was required? Was the task easy or demanding, slack or strenuous?
3. Temporal demand: How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?
4. Performance: How successful were you in performing the task? How satisfied were you with your performance?
5. Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?
6. Frustration: How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

A score from 0 to 100 is obtained on each dimension. Then, a weighting procedure is used to combine the six individual dimension ratings into a global score; this procedure requires a paired comparison task to be performed prior to the workload assessments. The comparison between different paired dimensions requires the subject to choose which dimension contributed to the workload level across all pairs of the six dimensions. The number of times a dimension is selected as more relevant represents the weighting of a specific dimension scale with regard to a given task for that subject. Finally, the global workload score from 0 to 100 is obtained for each rated task by multiplying the weight by the individual dimension scale score, summing across scales, and dividing by 15 (the total number of paired comparisons).

Table 16 - NASA-TLX

WORKLOAD (NASA-TLX)

How mentally demanding was the task?	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Very Low … Very High
How physically demanding was the task?	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Very Low … Very High
How hurried or rushed was the task?	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Very Low … Very High
How hard did you have to work to accomplish your level of performance?	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Very Low … Very High
How insecure/ discouraged/ irritated/ stressed/ annoyed were you?	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Very Low … Very High
How successful were you in accomplishing what you were asked to do?	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Very Good … Very Poor

Task questionnaire

Choose the factor that represents the more important contributor to workload:

Effort		Physical demand	
Mental demand		Physical demand	
Temporal demand		Frustration	
Performance		Frustration	
Physical Demand		Temporal Demand	
Physical Demand		Performance	
Mental Demand		Effort	
Effort		Performance	
Performance		Mental Demand	
Physical Demand		Frustration	
Frustration		Effort	
Frustration		Mental Demand	
Temporal Demand		Mental Demand	
Performance		Temporal Demand	
Temporal Demand		Effort	

Please explain which factors contributed the most to your experienced workload level:	

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Publications

A. International Conferences

Paper

De Piano, R., Ferreira, A., Pozzi ,S., Terenzi, M., Betti, V., Pavone, E., Marucci, M., Aricò, P., Borghini, G., Di Flumeri, G., Sciaraffa, N., Babiloni, F., Aglioti, S.M., Hurter, C., Benhacène, R., Clercq, C., Reynal, M. Telea, A., Kruiger, J.F. "Virtual Reality platform to assess air traffic controllers' performance in Control Tower Operations", *23 International Society on Virtual Systems and MultiMedia – VSMM 2017,* Dublin, Ireland, 31 October – 5 November 2017. (Accepted as poster)

Abstract

Ferreira, A.,Dokic, J. De Piano, R., Pozzi,S., Terenzi, M., Betti, V., Pavone, E., Marucci, M., Aricò, P., Borghini, G, Di Flumeri, G., Sciaraffa, N., Babiloni, F., Aglioti, S.M., Hurter, C., Benhacène, R., Clercq, C., Reynal, M., Telea, A., Kruiger, J.F. "Towards immersive and multisensory Remote Tower Operations: An explorative human-in-the-loop study using Virtual Reality", Transport Research Arena (TRA) 2018, Vienna, 16 – 19 April 2018.

Poster

Ferreira, A.; De Piano, R., Pozzi,S., Terenzi, M., Betti, V., Pavone, E., Marucci, M., Aricò, P., Borghini, G, Di Flumeri, G., Sciaraffa, N., Babiloni, F., Hurter, C., Benhacène, R., Clercq, C., Reynal, M., Telea, A., Kruiger, J.F. "MOTO-The embodied Remote Tower SID Poster Abstract (2017)" *SESAR INNOVATION DAYS (SIDs)*, 30 November 2017 (In progress).