ABSTRACT
Air Traffic Control has an intrinsic collaborative nature that should be addressed and considered in the design of novel technologies. A field study aiming to discover controllers’ collaborative actions within the control tower was carried out. The results of the study suggest that collaboration takes different forms, both explicit and implicit and that artefacts play an important role in supporting and mediating collaboration and communication. These elements represent a real challenge for the design of novel tools.

Keywords
Control tower, collaboration, artefacts mediation

INTRODUCTION
The work herein presented was carried out within the Augmented Reality (AR) for Tower Control project, currently running at the EUROCONTROL Experimental Centre. In order to carry out their job, the tower controllers use the so-called “look-out-of-the-window”, that is, maintaining visual contact with the traffic, by looking through the tower windows. However, visibility reduction imposed by adverse weather conditions or occlusion of parts of the manoeuvring area have negative impacts on the efficiency of the whole tower functioning, determining potential threats to safety and decrement in terms of traffic capacity (Bourgois, 2006).

The AR project aims to explore the potential of AR tools to support air traffic controllers (ATCOs) and to assess if AR would be suitable to support the tower tasks that, nowadays, can be limited or/and negatively influenced by poor visibility conditions. There are several arguments in favour of AR to reduce visibility-related problems. First, AR tools are made with the ambition of enriching what is actually seen by human operators with extra information, displaying and augmenting visual elements that are temporary invisible or permanently occluded. Second, AR could contribute to reducing the Head-Down-Time (HDT) problem. HDT involves the lack of optimal attention splitting between the primary information source for tower tasks (the look-out-of-the-window) and other assisting displays (Hilburn, 2004). With AR, information can be ‘superimposed’ onto the real visual data, thus ATCOs could simultaneously access both ‘artificial’ and real information, diminishing HDT effects.

In order to define the functional properties of novel AR tools for control tower, the understanding of ATCOs’ activities is essential. A preliminary examination of tower tasks was carried out, by analyzing the literature concerning task analysis studies for control tower (Alley et al., 1988; Dittman, Kallus & Van Damme, 2000; Rossi et al., 1996). The analysis provided an amount of interesting information with respects to visual tasks performed in the tower, that is, the specific operational tasks that mostly engage direct visual contacts. However, the investigations were essentially based on traditional task analysis and focused on a very narrow unit of analysis (the single controller performing a sequential series of tasks), collaboration between controllers was disregarded. Air Traffic Control (ATC) systems have a “socially organized character” (Bannon & Shapiro, 1994) and understanding the nature of this cooperation is essential to design effective systems (Bentley, Hughes, Randall, Rodden, Sawyer, Shapiro & Sommerville, 1992). Therefore, we decided to conduct a field study with the aim of studying controllers’ cooperative behaviours within the tower.

APPROACH AND METHOD
We decided to expand the object of analysis and to investigate the larger context of interaction of human beings with their environment (Marti & Scrivani, 2003). We adopted the theoretical framework of Activity Theory, a theoretical approach that derives from the socio-cultural theory founded by Vygotsky (1978). Specifically, Engeström’s activity theory model (Engeström, 1987) was used to guide the field study and structure the analysis. The model helped to capture the systemic relationships existing between the individual and her/his environment in a systematic manner. Ethnographic observations were carried out at the towers of two small airports (herein called Airport I and Airport II) of central Italy. Time constraints imposed by the project were quite strict and the observations were limited to nine days. The study concerned about 30 operators whose experience averaged the 28 years. We
obtained the permission of taking some pictures of the tools used in the tower but, because of privacy issues, video or audio recorders were not allowed. Thus, written notes were taken to record operational tasks, phraseology and also ATCOs’ personal comments and special care was used to write information as accurately as possible. The observations were complemented with informal interviews with the controllers, who provided explicit explanations of the actions, tools, sentences, and gestures used in the tower.

RESULTS
The information collected was quite heterogeneous, composed of written records of operational situations, controllers’ comments, drawings and pictures. The complete analysis and description of the general characteristics of every element of the activity system under study, of airports, tower layouts, and salient operational scenarios is given in an internal Eurocontrol document.

In general terms, the analysis of the results suggests that we can look at collaboration from the perspective of the controllers’ historical experiences in a specific context. The reference to history is herein used to support the idea that collaboration is the result of a process that develops over time, first during ‘formal training’, and then during on-the-job training, when ATCOs integrate the normative competencies in real-traffic conditions, within a specific setting. Along with the normative procedures and constraints of the local environment, the controllers acquire familiarity with the tower local organization, with the other actors operating in the tower, with the informal rules and practices shared by the local community of controllers.

FLEXIBILITY: ADAPTING WORK TO CONTEXT
There are some ‘standard’ controller working positions that traditionally characterize roles and duties within the tower: 1) the Tower Controller (TWR) is responsible for the operations on the runway (RWY) and aircraft flying within the area of responsibility of the aerodrome control tower; 2) the Ground Controller (GND) is normally responsible for traffic on the Taxiways (TXYs). However, during the field study we discovered that roles’ attribution and individual responsibilities do not follow rigid prescriptions, but are tailored to local requirements.

In the tower of Airport I there is an Executive controller (EXC) and a Coordinator (CRD). The EXC is responsible for traffic operating on RWYs, TXYs and/or flying within a designated portion of the aerodrome airspace; the CRD is responsible for making telephone coordination (to negotiate aircraft hand-over) with adjacent control units. In the tower of Airport II, there is an EXC and an Approach controller. The EXC is mainly responsible for the traffic operating on RWYs and TXYs; the Approach controller manages inbound and outbound traffic within a large volume surrounding the aerodrome airspace and makes telephone coordinations with the neighbouring control unit. The specific characteristics of the two aerodromes in terms of traffic volumes and airport design had determined the construction of peculiar roles (encompassing the traditional TWR and GND positions), which can better respond to the local traffic requirements.

Different positions for different roles
Whereas in the tower of Airport I the EXC and CRD work side by side (and they are both ‘facing the RWY’), in the tower of Airport II controllers are clearly separated: the EXC sits just in front of the RWY, and the Approach controller is displaced, approximately 90° to her/his right (cf. Fig. 1).

Figure 1: Roles configuration
This different arrangement of the tower roles was brought about by operational and airspace design constraints. More precisely, the airspace controlled by the Approach controller of Airport II is quite large, it is flexible and can be expanded or contracted in accordance with the negotiations performed with the adjacent control unit. This flexibility (as well as the necessity of frequent telephone contacts to negotiate aircraft hand-over) made necessary the definition of a specific position, physically isolated from the EXC.

IMPLICIT AND EXPLICIT COLLABORATION
The physical position of the controllers working in each tower seems to have an impact also on the forms of collaboration taking place in the towers. The close proximity of ATCOs in the tower of Airport I enhances natural joint monitoring of the current state of affairs. The strip bay is placed in front of both controllers and, as the paper strips ordering on the strip board is a tangible account of the current (and future) traffic situation (Marti & Scrivani, 2003; Bentley et al., 1992), both controllers can share a common representation of the traffic status. In addition, ATCOs’ physical proximity allows to easily grasping the colleague’s conversations over the telephone or on the radio. These simple ways of sharing information allow recognizing and anticipating colleague’s intentions and needs in a contextualized manner.

In the tower of Airport II ATCOs’ physical positions seem to trigger more explicit forms of collaboration, which are often mediated by spoken requests. However, controllers have the tendency to lessen explicit cooperation because (as also acknowledged by ATCOs) it is important to understand, predict, and proactively take action in order to support colleagues, without their explicit requests. Indeed, forms of collaboration aiming
to tacitly support the colleague’s tasks were also observed in the tower of Airport II. For example, in some occasions the radio communications with pilots were switched to loudspeakers. Without the hindrance of headphones (normally used in towers) ATCOs were more easily informed of the current state of affairs, could envisage future traffic requirements and perform appropriate actions supporting the peer, despite the physical distance.

**Knowing the others**

An important condition for tacit collaboration is the controllers’ mutual acquaintance. A controller stated that: “it is important to know each other in a team, recognising the mood of the partner too ... knowing how he writes and what he writes on the strips, for example I write many abbreviations ... for Villafranca, I write V F ... Some controllers are very precise in writing, they write everything, some others keep a lot of things in memory, then you have to ask things”. Knowing the colleagues means being familiar with the personal working style of the controllers operating in a specific setting, structuring expectations about the others, and establishing trustworthy relationships.

**THE CREATIVE SIDE OF ATC**

When asked about the meaning of the ordering of the paper strips on the strip bay, a controller stated that: “yes, the order is important too... during the [training] course we have special session dedicated to strips manipulation, but then you adapt a bit, you make it more personal, it is important to work well ... so if it works well or better it is fine”. The personal characterization, adaptation, and even the creation of new artefacts articulates the presence of contradictions within the activity system and constitutes a process of transformation that takes place during the development of the activity itself; if artefacts creation (or adaptation) seems to “work well or better”, the new tools are integrated and shared within the community of practice.

**Runway occupancy status**

An interesting example of creation of new artifacts is given by tools used as memory aids for the RWY occupancy status. A pre-requisite for the execution of landings and takeoffs is the verification of the RWY status (occupied or vacated). The RWY can be occupied not only by aircraft, but also by other vehicles. As a matter of fact, the company responsible of the airport operations (few times per day at both aerodromes) executes RWY inspections in order to verify the functioning of the lighting system or to check the presence of objects or obstacles. Forgetting about the presence of vehicles on the RWY is a serious threat to safety. During the observations, we discovered how ATCOs cope with this problem. Indeed, some controllers of Airport I were able to mention different solutions that were adopted during the years. Initially a luminous indicator had to be turned on by the controllers all the times that a vehicle occupied the RWY. However, this solution was not very successful. An ATCO reported that: “despite the clear visibility of the led, sometimes we were simply forgetting about it ... we were also forgetting of turning it off when the RWY was vacated”. The problem is that turning on the indicator was extraneous to the work activities and a solution coherently integrated in the work was necessary. An alternative solution consisted of a thick colored card shaped as a “no entry” sign, which could be attached to the radio microphone (cf. Fig. 2).

![Figure 2: RWY check](image)

This crafted artifact was more efficient, in that it physically affected the execution of a basic ATC task: speaking to pilots. The last solution, currently implemented in both towers, is a special paper strip, which is placed on the strip bay whenever a vehicle occupies the RWY, and removed when the RWY is vacated. This frugal artifact is meaningfully integrated into the work practice, it is an effective memory aid and it is consistently maintained. In addition, it serves as an unambiguous means of implicit communication between ATCOs. For instance, during the shift change controllers do not even need to tell the colleagues that the RWY is occupied, the controllers naturally “look outside and look at the strips”, and by looking at the strip board they will simply know.

![Figure 3: Special paper strip for the RWY check](image)

**Maps, charts and the red pen**

There are two more examples of artifacts creation and adaptation that deserve to be mentioned. The first example is common to both towers and entails the use of the working desk. ATCOs have placed maps, charts and other written materials under the transparent glass covering the working desk (cf. Fig. 3). When questioned about the meaning of this documentation, ATCOs declared that maps and charts should be always and easily available. In particular, maps are important for novice controllers who, during on-the-job training, are gradually building their knowledge of the aerodrome.
surroundings and, for example, might need to verify the geographical position of pilots’ reported points. The second example entails ‘slotted aircraft’ and was observed only in the tower of Airport I. Slot allocation is a measure established to smooth out traffic flows. A slotted aircraft is required to be ready for departure within a certain time and ATCOs must conform to this requirement. In the tower, there are several ‘slotted aircraft’ per day and ATCOs use a red pen to mark them on the paper strip. Aircraft with a slot are usually given priority and red annotations are a means to remind that this operational constraint has to be considered in the traffic sequencing and organization.

IMPLICATIONS FOR THE DESIGN
The results of the present study have several implications for the design of AR tools for control tower. AR tools should not be built on the basis of standard roles’ configurations and rigid physical placements, but allow flexible arrangements, adaptable to local operational requirements. Novel tools should be non-intrusive and allow free physical contacts between controllers (such as visual contacts or overhearing dialogues). Knowledge sharing can be enhanced or hampered by physical constraints, AR tools should on demand provide or augment information that is currently not available to the controllers who need it (for example, because the physical distance does not allow to promptly access it).

Collaboration is often externalized in the use of artifacts: some are used for purposes other than that for which they were originally intended and, even more interestingly, the controllers can adapt them (or conceive brand new tools) when available artifacts do not properly support the activity.

These artifacts are quite simple, based on old-fashioned hardware (paper and ink), but they are tangible, reliable, well integrated within the practice and constitute a pool of trusted resources, used by every controller working in the tower. Moreover, they allow a flexible manipulation and offer opportunities for learning and enhancing the activity.

Novel technologies should capture, re-think and augment the role of these frugal artifacts, allowing the creation and modification of customized tools that can be shared within the controllers’ local community.

ACKNOWLEDGMENTS
The present work was supported by the EUROCONTROL Experimental Centre, under contract No. C61PT/2004. The views expressed herein do not necessarily reflect the official views or policy of the Agency.

REFERENCES


