PUBLISHABLE FINAL ACTIVITY REPORT

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1 EXECUTIVE SUMMARY

The management of air traffic across the wide areas used in international routes is a growing problem with the increasing numbers of passengers and flights in operation. The systems used for ATM are adopting new technologies quite slowly and the modern controller uses working environments similar to that in use for more than 30 years. Despite the fact that the management of air traffic is partly a three dimensional problem and the long discussions about the benefits, no extensive use of 3D technologies has been made to date.

The key objective of the AD4 project is the enhancement of a 3D Virtual Reality system, called D^3 (D-cube), for the real time visual representation and manipulation of data in the field of Air Traffic Management and Control, both in open space (en-route and approach) as well as at Airport level. The D^3 technology is capable to manage a real-time 3D visualization and navigation by means of the adoption of an open distributed infrastructure able to handle dynamical and scalable data elaboration and integration using auto-stereoscopic displays and 3D mouse devices.

The targeted AD4 system is being designed and implemented in collaboration with experts in field of ATM systems, VR developers, Human factors and the Italian Agency for Air Navigation Services – ENAV, producing a specific demonstrator that will enclose real interfaces and data coming from a Traffic Centre and Simulation environments and will be extensively evaluated by air traffic control personnel. The AD4 infrastructure shall enable to determine what benefits, in terms of enhanced understanding and clarity of perception, 3D displays and/or 3D representations in 2D displays, combined with enhanced information presentation, can provide to the controllers in Approach and Tower sectors. It is hoped [has highlighted in recent studies] that improvements in this area will permit more efficient and safe management of more aircraft over a wider airspace.

The projects aims to explore the application and benefits of 3D (stereo) VR display and interaction technologies with a view to determining the qualities required to produce an effective 3D information visualization environment for the air traffic controller. The implemented system, targeted at semi-immersive displays such as auto-stereoscopic displays/ projector and VR theatres, will make use of VR techniques to provide an environment within which an air traffic controller can observe and monitor a large number of aircraft over a wide area, being kept aware of the many complex factors about their planned routes which may affect the future planning of the flight paths, and can use 3D interaction methods to select and re-route aircraft interactively as the data are updated in real time.

To provide an effective test-bed for 3D VR interaction and visualization in air traffic management the consortium will based on robust, distributed and real-time system which can provide a controller with a 3D environment showing all of the aircraft active in the controller's particular region of interest and those whose routes will take them through it during their flight time. The flight information that will obtained should provide a complete set of inbound and outbound flights across the International Ciampino Airport (the second Rome airport, where the CRAV centre supplies control to a wider area centered in Rome) and will include a range of different aircraft types and flight distances and shall be integrated with Eurocontrol ESCAPE platform for simulation facilities.

1.1 DESCRIPTION OF WORK

Future scenarios do not simply involve an increase in air traffic; in addition new forms of co-operation and co-ordination are expected to emerge. New IT technologies and platforms afford more data to be available to many of those who run the whole ATM system. As the human factors literature suggests, the availability of more data implies new forms of task distribution and thus new co-operative strategies have to be anticipated. This implies a paradigm change when designing for new technological support. A novel 4D approach, that we call D4 – to differentiate with the existing 4D ATM concept - creates new opportunities in the way the controller will visualize and interact with information: new ways of representing the information, while not necessarily decreasing workload, provide an opportunity to reduce existing knowledge gaps, supporting optimal decisions making (as demonstrated in recent works).
In this context, the AD4 project aims to build an innovative Virtual Air-Space representation for ATM system, providing a range of valuable benefits to support efficient control systems where 3D real time interaction with air traffic/airport space is accessible to the controllers.

The AD4 project is of a duration of 26 months addressing the analysis of Operational Concepts and Human Factors, the engineering of the IT infrastructure and its core Components (4D HMIs, Middleware, Predictive and Applicative Components, Interfaces to external data e.g. Meteo and ATM system integration), the development the working Demonstrator for an operative context, the validation by the use of the MAEVA methodology and the assessment and exploitation of results. AD4 is based on extensive use of a technology called **D^3** (D-Cube), originally developed in a successful National project co-funded by the Italian Space Agency ASI. Such technology supports dynamic management and scalable data elaboration for DEM, Meteorology, Pressure and Wind fields, Radar tracks and Telemetry data using auto-stereoscopic displays and 3D mouse devices.

The AD4 system is implemented in collaboration with experts in field of ATM systems, Virtual Reality, and Human factors supported by the Italian Agency for Air Navigation Services ENAV, targeting:

- A definition of the Operational Concepts and their expected impacts, including a review of the State-of-Art technologies and systems,
- A careful study of the major aspects related to the next generation 4D HMIs, driven by an extensive analysis of the Human Factors and an extensive assessment of safety and security aspects;
- The construction and on-site integration of a demonstrator in a real ATM control centre, tested by air traffic controllers;
- The appointment of two Workshops, involving major players of the field and key users, presenting preliminary results and the final outcomes of the AD4 project;

The AD4 project built different releases of the IT infrastructure integrating 3D technologies and ATM components, driven by Models by the use of OMG Model Driven Architectures and making use of Component Middleware (CORBA CCM). Final demonstrators are hosted by a real ATM experimental centre and tested by air traffic controllers.

Dissemination material will be published in a dedicated web site **http://www.ad4-project.com** to circulate important results in the relevant ATM communities.

The AD4 system is offering a "**global vision**" of the traffic flow that the controller has to organize, in order to balance it among two or more sectors. The 3D display supports the controller in the definition of such a balanced flow between the sectors, that is, the creation of segregation between flows, following a sort of "what if" strategy. At a visualization level, the 3D display is providing a wide overview of the air traffic and supports the process of balancing the workload among the sectors. The 3D immersive virtual reality displays are shown to be useful in allowing capturing a global image of the traffic and integrating in a single screen the 4 dimensions of the traffic problematic. The system allows rapid and dynamic interaction with the scenes represented. Users could, as an example, zoom certain spots of traffic, perform rotations and translations of the scenes, interact with 3D/4D widgets and controls and have easy access to different point of views within the traffic flows. Seemingly, these wide interaction capabilities allow the dynamic appreciation of air traffic details, which are judged quite relevant for the activity. The sectors' traffic allocation is an interesting proposal and it also represents an original and unexplored application domain for 3D.

A **3D Radar Display** novel in the field, allows choosing the different layers of data that are embedded in the Virtual Scenario, represented in 3D with the aid of immersive technologies. Incremental and fluid navigation, limited only by the complexity of the rendering area (mitigated by on-demand selected modification of the local objects in the scenario – the so-called immersion of singleton objects) is achieved. Within this environment we make use of 3D/4D interaction devices both to navigate in the scene and to select and manipulate flight information within the scene. The user's viewpoint is typically centred on a point of interest (initially located at the airport) but can be updated to centre on any position by simply pointing and clicking using a 3D mouse pointer. The same device will then be used to control rotation of the camera around the view centre in two degrees of freedom and zooming of the view. The presentation of relevant views of the approach as well as the tower sectors helps to demonstrate the feasibility of using novel approaches to the construction of system to support ATC operations.

The AD4 project and its consortium

The AD4 project is co-funded by the European Commission – DG-Research Aeronautics and Space and its consortium is composed of key players in the field. The AD4 system is designed and implemented in collaboration with experts in field of ATM systems, VR developers, Human factors and the Italian Agency for Air Navigation Services - ENAV. The Consortium includes research as well as industrial partners committed to the acquisition and development of the advanced technological know-how required to address the project objectives and to the exploitation of the results achieved throughout a specific ATM infrastructure and a definite demonstrator. Final users and testers of the targeted ATM field are also key contributors to the project development and assessment: they have produced specifications of real operational needs within their business cases and coordinated the final phase of testing and validation of the prototype.

The Coordinator of the project is the Italian **NEXT-Ingegneria dei Sistemi SpA** that acquired a significant experience in innovative technologies working in projects for the Italian Space Agency, the European Commission and the GALILEO Joint Undertaking. Relevant contribution and support was made by the Italian Company for Air Navigation Services **ENAV**. **Vitrociset** (I), **SICTA** (I) that provided components and simulators for ATM context based on ATRES and ACE platforms respectively, **Space**

Application Services (B) that contributed to the Visualisation technology and developed with NEXT the Augmented Reality Proof of Concept, **Digital Video** (I) that contributed to the Visualisation technology and **ESI** (E) that studied the Engineering Process; **Fraunhofer Fokus** (D), **Object Security** (UK) devoted their work to the MDA driven architectures, IT security and middleware. The **University of Middlesex** (UK) supported the Human factor analysis and the assessment of results.

1.2 ACHIEVEMENTS, THE AD4 PORTFOLIO

The AD4 project, aiming to build a Virtual Air-Space representation for ATM systems, has faced several and different aspects, going from the development of secure middleware and distributed component-based IT infrastructure to application of 3D representations and Virtual/Augmented Reality techniques in the ATM domain, passing through the definition and implementation of a MDA (Model Driven Architecture) Tool Chain to support the AD4 development life-cycle.

The following picture, summarizing all the aspects covered by the AD4 project, illustrates the so-called "**AD4 Portfolio**" of solutions.

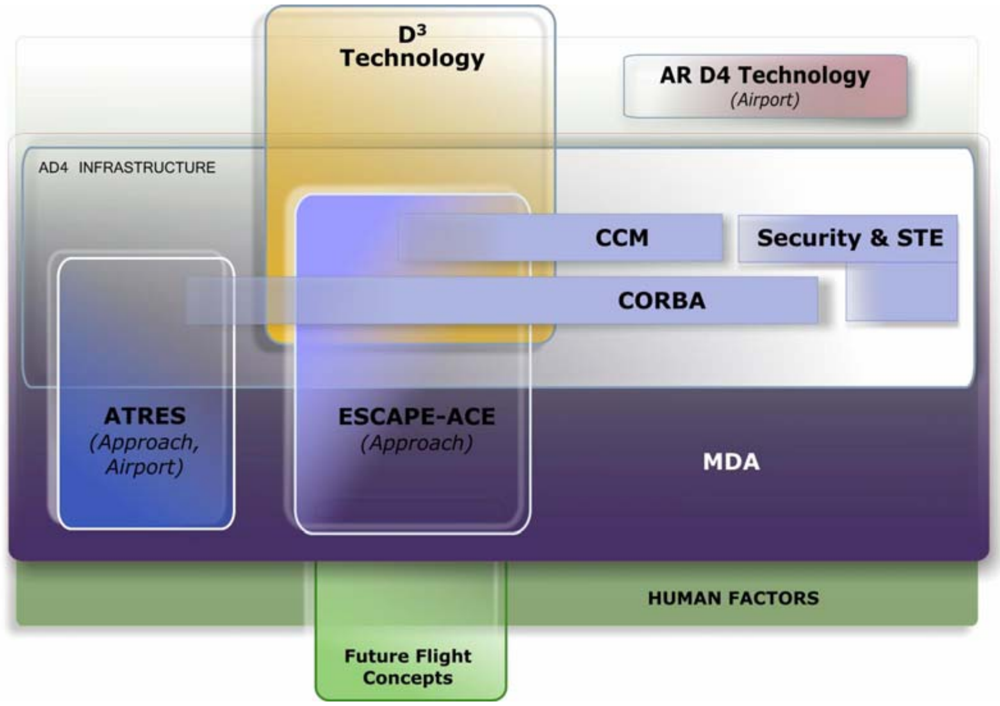


Figure 1. The AD4 Portfolio

The elements, solutions and achievements of the AD4 portfolio, developed in the course of activities, are illustrated below. It is worth to be noted that the project Consortium was able to design, implement, test and validate all the elements of the AD4 platform with the support of lung run RTHL simulations carried out with the support of Controllers. The results of the project are in line with the envisaged SESAR activities and beyond.

The D^3 technology: the Virtual Airspace representation into the 3D Radar Display

The AD4 3D Radar Display provides an innovative **Virtual Air-Space representation** for ATM systems, where **3D representations of air traffic/airport space** and virtual/augmented reality techniques are accessible to the controllers.

The AD4 Virtual Airspace representation is based on the display of visual elements within a purely synthetic 3D Virtual Environment that provides a 3D perspective view of the ATC controlled sector. The implementation of such 3D Virtual Environment is based on a 3D framework, called D^3 (D-cube) developed by NEXT in a national research project. Such framework has been successfully enhanced and tailored to the ATC domain in the course of the AD4 project.

D^3 is a 3D Virtual Reality system for real time visual representation and manipulation of heterogeneous geo-referenced data such as DEM (terrain), meteorological data (clouds, pressure and wind fields), telemetry data, GNSS (satellite) and surveillance data (radar tracks). Such data, coming from different sources, are merged and represented in a 3D manner:

- **GTOPO30** and **SRTM** (Shuttle Radar Topography Mission) data are supported for Digital Elevation Models of terrain
- **Meteosat OpenMTP** and **METAR** formats are supported for meteorological data
- **DAFIF** (Digital Aeronautical Flight Information File) format, as well as proprietary formats, are supported to access data on airports, navaids, waypoints and other airspace elements
- **ASTERIX** cat.062 is supported to access surveillance radar data
- **CORBA IDL interfaces** for the ATC domain (e.g. **AVENUE**) are supported to promote interoperability among platforms.

D^3 framework is capable of both 3D Visualisation and 3D Navigation.:

- **3D visualization** results from the integration of heterogeneous data, structured into layers. Throughput and elaboration limitations are overcome by a scalable and distributed architecture.
- **3D Navigation** is allowed by the use of both specific and standard input devices.
  In particular 3D Mouse, a 6 degrees of freedom device, is supported to allow controllers to “fly through” the airspace.
  Map-based navigation and view-point selection techniques have been developed to ease the use of the 3D environment by controllers.
  3D navigation with standard mouse is also possible by the decomposition of 3D navigation into a series of 2D mouse gestures.

The AD4 3D Radar Display allows to display all the phases of a flight allowing to follow aircraft from gate to gate.

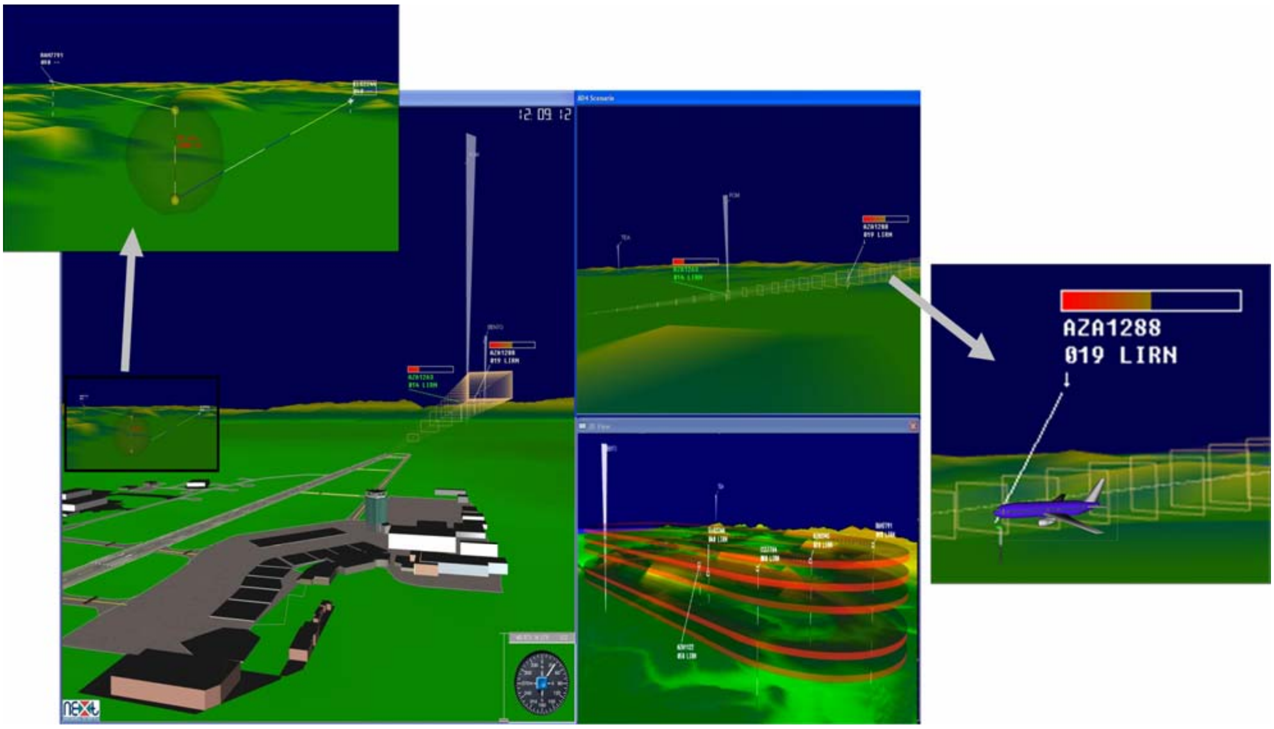


Figure 2: AD4 3D Radar Display overview

The picture above gives an overview of the AD4 3D Radar Display, illustrating the 3D airspace representation adopted in AD4 together with additional windows used to control the system.

The AD4 system provides a 3D Display of the controlled environment, including **3D representation of constraints** (terrain, radar minima, military restricted airspaces, clouds) and **airdromes**. 3D representation of **waypoints** and **airways**, **holding stacks**, **landing paths** and **ILSs** are supported in order to provide controllers with a reconstruction of airspace.

Display capabilities of the AD4 system are summarized in the following list:

- 3D Display of the controlled environment (Airspace, particularly the Approach phase, and Airport environment) including constraints (terrain, radar minima, military restricted airspaces, clouds)

- 3D Display of visual elements aimed to improve controllers situation awareness in the APPROACH sector
  - **aircraft trajectories intersection** with vertical and temporal separation at the intersection point
  - **holding stack** nominal volume, presence of aircraft in the stack (holding stack flight levels occupancy) and foreseen time to exit from the holding circuit
  - intersection between aircraft trajectories (both real and hypothetical) and **military restricted airspaces**. Time to the intersection point is displayed as well.
  - **hypothetical trajectories** (*what_if* trajectories)
  - intersection of hypothetical and real aircraft trajectories with vertical and temporal separation at the intersection point
  - relative position of aircraft trajectory against **ILS** volume

- 3D Display of visual elements aimed to improve controllers situation awareness in the Airport environment
  - **taxiways** and **runways**, represented in different colours to show different states (e.g. free, occupied);
  - **3D gates** located along runways and landing paths, to show the position of critical points (points of no return) for landing and take off manoeuvres
  - relevant 3D **buildings** and **parking areas** (apron).
  - 3D shape of aircraft, represented by a simplified geometric model, but with real size of actual aircraft;
  - identification **labels**, associated to each aircraft and providing the relevant data such as the aircraft type, the call-sign, and other auxiliary information;
  - a vertical segment (or an arrow) representing **aircraft acceleration** and a horizontal one representing **stopping distance**;
  - aircraft **projected volume** to show the foreseen occupied volume along the expected direction of motion, in a given time;
  - visual alerting mechanisms to display different sorts of **runway incursions**

The AD4 Infrastructure and the integration of Simulation platforms (ESCAPE/ACE and ATRES)

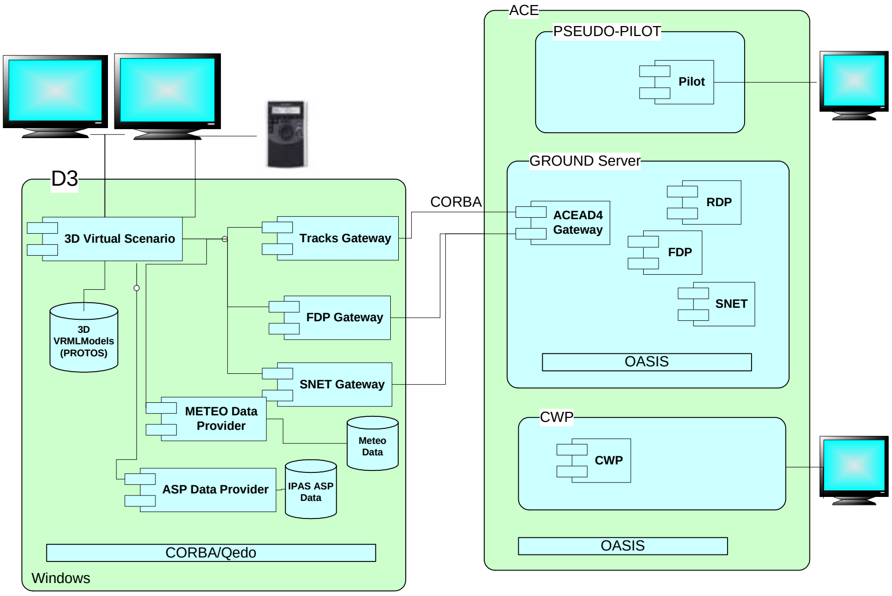
The AD4 infrastructure makes use of Distributed Computing with remote heterogeneous components providing data to be processed and/or displayed. In this context heterogeneity refers both to data (radar tracks, flight plans, weather and terrain data provided by different components running on different machines) and the way these data are provided (the use of TCP/IP protocol with exchange formats or Distribute Object Computing Middleware like CORBA are common approaches used in the ATC context).

A strong emphasis has been placed on the definition and development of a robust and open IT infrastructure with the aim to build on it a distributed and component based 3D command and control system based on **secure middleware** (**CORBA** and **CCM**), supporting standard exchange formats (e.g. ASTERIX) and allowing the interoperation with ATC components and simulation platforms like the Eurocontrol ESCAPE-ACE (Avenue Compliant ESCAPE) and Vitrociset ATRES platforms.

D^3 platform has been successfully integrated with ATC simulation platforms. The result is the availability of two different integrated systems (D^3-ACE and D^3-ATRES) ready to be used as a test-bed for current and future assessments on the use of 3D in the ATC context for both approach and airport phases of a flight.
Such integrated systems have been used in the final part of the project to conduct Real Time Human-in-the-Loop Simulations aimed to evaluate safety, usability and acceptability of the proposed AD4 4D Human Machine Interface.

The **ACE platform** was successfully used to
- simulate air traffic to implement Approach Operational Scenarios relevant for the evaluation of the AD4 4DHMI concept in the Approach control.
- conduct air traffic simulations
- demonstrate the capability of the AD4 system to display approach scenarios

The **AD4-ACE integrated system** was successfully used during Real-time Human-in-the-loop simulations at SICTA premises with the involvement of operational air traffic controllers to evaluate the AD4 concept.



CCM components were successfully implemented to achieve the integration between AD4 and ACE.

Such integration involved development activities on both the ACE side (development of components based on the OASIS middleware) and on the AD4 side (development of components based on QEDO). In detail the following set of gateways were developed to ensure the AD4-ACE interoperability :

- on the ACE side
  - a gateway (an ACE component) that subscribes to the ACE platform and forwards events to AD4
- on the AD4 side
  - a gateway for receiving radar tracks updates from ACE
  - a gateway for receiving flight plans data, both initial and updates, from ACE
  - a gateway for receiving correlation data from ACE
  - a gateway for receiving supervision events and simulation time from ACE
  - a gateway to get Area Proximity Warnings, Short Term Conflict Alerts and Minimum Safe Altitude warnings from ACE (safety net)

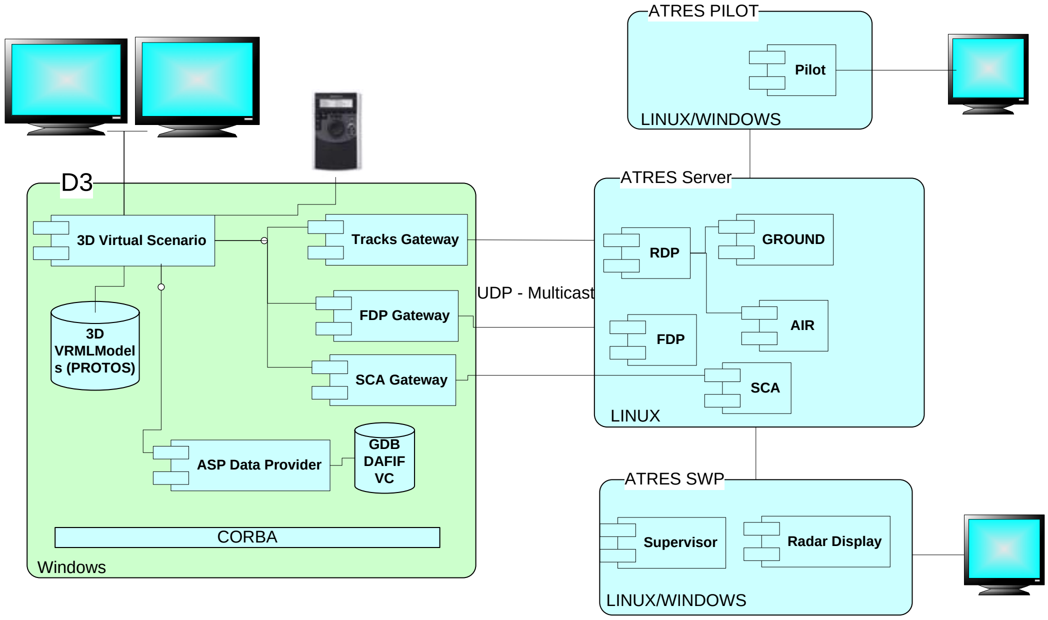
The Qedo controller was used to start-up, control the Qedo runtime environment and deploy AD4 Qedo components. All the AD4 Qedo components were packaged into a single CCM assembly package.

The **ATRES platform** was successfully used to

- simulate airdrome movements in order to implement Control Tower Operational Scenarios relevant for the evaluation of the AD4 4DHMI concept in the ground and tower control.
- conduct air, ground (airdrome) and combined (air + ground movements) simulations.

- demonstrate the capability of the AD4 system to display approach + tower integrated scenarios
- demonstrate the capabilities of the AD4 system to act as a 3D Radar Display and interoperate with external data feeders able to provide data in standard formats (i.e. ASTERIX cat.062)
- implement a "mobile" demonstration system to be used at exhibitions and dissemination events. In fact the AD4-ATRES integrated system was successfully used at AeroDays 2006, INO Workshop 2006 and ATC Maastricht

The **AD4-ATRES integrated system** was successfully used during Real-time Human-in-the-loop simulations at SICTA premises with the involvement of operational tower and ground controllers to evaluate the AD4 concept.



AD4 components were successfully implemented to achieve the integration between AD4 and ATRES. Such integration involved development activities on both the ATRES side and on the AD4 side. In detail the following set of gateways were developed to ensure the AD4-ATRES interoperability :

- a gateway for receiving radar tracks updates from ATRES
- a gateway for receiving flight plans data, both initial and updates, from ATRES
- a gateway to get Surface Conflicts Alerts from ATRES (SCA)

The Component model approach

CCM (CORBA Component Model) is one of the best platforms for developing large scale distributed systems. It is based on the mature CORBA middleware and adds some more advanced concepts. It also simplifies the usage of some CORBA Services.
CCM enhances the Object Model of CORBA. In CCM a component has a component interface (equivalent interface). This interface provides operations for introspections and navigation regarding other components features. A component can provide a set of facets. A facet is a

named port providing a specific interface. Clients of this component call operations on a facet. The facet's counterpart, a receptacle, is a named port where a specific interface can be connected to. A facet of a CORBA Component in server role can be connected to a receptacle of a CORBA Component in a client role. Receptacle ports make dependencies to other interfaces explicit, which helps to minimize wrong configurations and run-time failures by providing type safety.

Qedo is an open source tool suite that provides the development support, runtime environment, and deployment infrastructure for CORBA Components. The name Qedo stands for "Quality of Service enabled distributed Objects" and reflects the broad scope towards a component platform fulfilling the requirements of complex applications. The foundation of this is the CORBA Component Model specification defined by the OMG. Qedo is an implementation of this specification and offers a variety of extensions (e.g. QoS) to address specific needs of particular domains.
Qedo fully supports the component-based development cycle, namely: you can design, implement, compile, package, assemble, deploy, install, instantiate, configure, execute, and manage distributed CORBA component-based applications.

Qedo has been improved during the two years of the project: several bugs have been fixed in new versions (Version 0.8.3 from June 2006 and Version 0.9.0 from November 2006).

Qedo/MICO was successfully used to develop and deploy CCM components acting as gateways towards the ACE platform. Interoperation issues towards the middleware used in ACE (OASIS, based on ORBIX) were successfully faced and solved.

<u>Security and the secure Middleware</u>

Security task studied and defined concepts for integration of Security Architecture into Qedo and the AD4 Tool Chain. The middleware version developed and/or extended in the framework of the AD4 project is called Secure Middleware.

Secure Middleware in AD4 is composed of

- MICO, CORBA ORB with improved support for security
- Qedo, CORBA Component Model implementation with enhanced Quality of Service support
- OpenPMF, Policy Management Framework
- ObjectWall, IOP Proxy for firewall traversal and domain boundary protection

MICO is well known as a stable ORB for standard client/server type applications. MICO was improved in the framework of the AD4 project to support a much more distributed architecture and much more in- and outgoing connections between the ORBs. The overall stability of the ORB was greatly improved even under very demanding conditions, for example on very fast SMP systems.

OpenPMF is the policy management framework used for the definition, management and enforcement of security policies. The PDL (Policy Definition Language) generator was implemented as a part of the tool chain and automatically generates high assurance security policies from platform-in depended models.

ObjectWall is an IOP Proxy for firewall traversal and domain boundary protection.
ObjectWall was used for the implementation of the **Secure Testing Environment** (STE), an integration of the Escape simulation system running at SICTA (Naples) and the 4D display at Next (Rome). The STE consisted of ObjectWall instances collocated with SICTA's and Next's firewalls. The STE allowed to securely send flight data from the Escape installation at SICTA over the Internet to the AD4 visualization system under development at Next.
The STE was successfully used to test integration between the AD4 and ACE platforms in a remote way. By its use it was possible to get data remotely by invocation of CORBA operations through the ObjectWall Domain Boundary Controller.

Engineering, Life-cycle and MDA aspects

The AD4 Life-Cycle development process, starting from the analysis of standard lifecycle processes and techniques, has defined the AD4 lifecycle aimed at helping coordinating resources to achieve predictable results. A good lifecycle process provides guidelines and techniques to structure the work, increases the odds of being successful, and therefore provides value to the organization, the project and the project team. The value of using a lifecycle process appropriate for the project consists in ensuring that all of the necessary work is included in the initial estimates and the initial work-plan, helping ensure that planning is done before execution in all steps of the lifecycle and providing a basis for learning from and taking advantage of pre-existing processes, techniques and templates.

In order to manage the risk of imprecise and/or incomplete requirements as well as the implementation of inappropriate 3D/4D representation forms, a **lightweight iterative development process** has been adopted. Iterative development prescribes the construction of initially small but ever larger portions of a software project to help all those involved to uncover important issues early before problems or faulty assumptions can lead to disaster.
The adoption of such a development process type allows AD4 developers to focus on a small number of requirements a time giving them the possibility of producing the final system incrementally. New features are so added to an executable prototype made available in the early stages of the project Features implemented at previous iterations can be revised on the basis of user feedback.
A methodology to be used in AD4 to drive each "internal" development iteration was so defined (according to the definition of the AD4 life-cycle, each official release is composed of a certain number of "internal" iterations). Such methodology defines and makes use of a Requirement Matrix that lists all the requirements (as specified in the System Requirements report) assigning them a priority, a status, a feasibility judgment and allowing their traceability through the identification of dependencies and involved architectural components.

As already mentioned, the AD4 project has defined a life cycle

- being component based
- supporting model-based development

The AD4 tool chain, implemented in the course of the project as part of the life cycle development activities, allows us to combine these two aspects providing a proper modelling infrastructure based on the MDA (model-based development) paradigm and targeting CCM components (component based development) as the basis of our development effort.

In fact in the AD4 project physical components have been developed (from design to implementation) by using the AD4 tool chain, which provides an integrated development infrastructure for AD4 physical components.
The AD4 tool chain supports the MDA approach. This means that the AD4 system infrastructure can be modelled independently of the implementation platform, there is no need to model, e.g., platform-specific data types, or to make decision immediately which platform to take. By using transformers AD4 PIM models can be automatically transformed into the AD4 PSM for further steps (e.g. code generation).

The architecture of the AD4 Tool Chain is shown below:

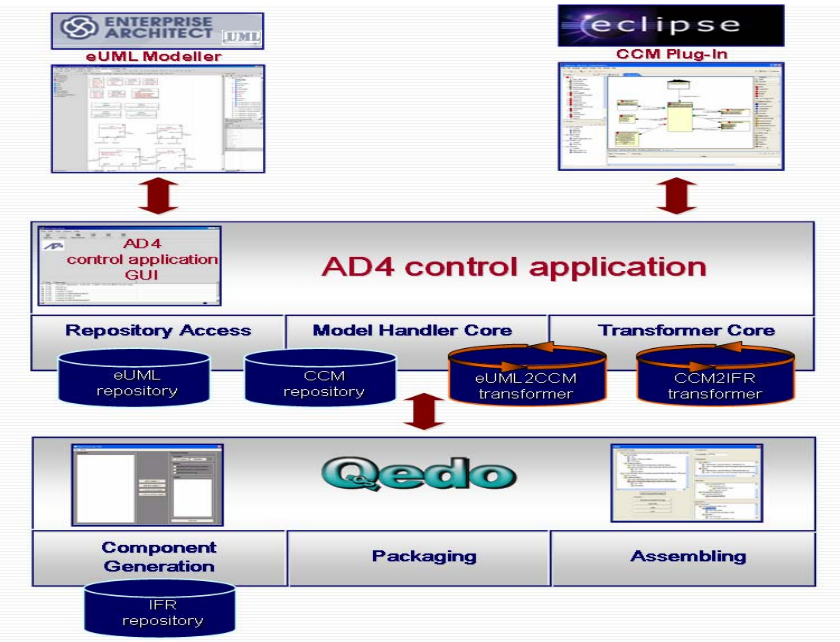


Figure 3: Overview of the AD4 Tool Chain Architecture

The AD4 Tool Chain supported development activities by the automatic transformations of Platform Independent Models to Platform Specific Models targeted to the CCM platform and of Platform Specific Models (making use of UML2 profile for CCM) to Qedo enabled source code.
Among the others the AD4 Tool Chain is capable of

- Tool chain - Security integration through additional transformations aimed to produce PDL (Policy Definition Language) security policies
- IDL import to allow the use of pre-existing IDL interfaces and data structures in Platform Specific Models (this feature was used to import ESCAPE/ACE IDL interfaces into models of the AD4ACE gateways)
- Assembly modelling and transformation
- Assembly package creation (to replace the QXML tool being part of the Qedo Tool Suite)
- Refactoring of models (propagation of the change of an attribute name, propagation of the change of the signature of an operation)

Augmented Reality

The purpose of the AR demonstrator is to prove applicability of the AR visualization technology in the development of an HMI for tower controllers, while taking into account some of the main 3D/4D visual concepts that derive from the needs of the Operational Scenarios identified in the AD4 project. Those 3D/4D concepts are partially revisited and utilized for the AR HMI, which thus appears to be strictly related to the D3-based Tower HMI.
The capabilities of the demonstrator are mainly focused on visualization, rather than interaction; indeed, AR provides a way to visually augment the real world perceived by the controller with synthetic 3D elements generated by the system. 3D synthetic (virtual) objects are rendered and displayed in a perspective view, which is overlapped to the real one, according to the real viewpoint and field of view of the user.
Augmentation consists not only in representing the 3D models of real objects (e.g. to replicate a wire-frame 3D aircraft or building on top of the real ones), but also in introducing new elements, such as aircraft labels or time-related 4D (3D space + time) visual elements (e.g. future position of aircraft, acceleration,…) that can provide additional information to the user about the real scene being observed.
Interaction is mainly concerned with the selection of those synthetic data layers to be displayed, i.e. the controller is allowed to enable/disable 3D/4D virtual objects, and the general visualization settings.

From the technological point of view two different approaches have been identified as possible candidates: a full AR approach and a simplified one.

- Full AR approach consists in the use of head tracking devices, to track user's view-point movements, coupled with semi-transparent display devices where to present synthetic images registered with real objects (present in the real world).
- Simplified AR approach consists in the use of video cameras placed at fixed positions in the airport and standard monitors to display synthetic images superimposed on images coming from video cameras. No tracking devices are used and 3D scene is reconstructed from fixed camera position, orientation and field of view.

The opportunity of achieving a rapid development of the AR experiment and non-intrusiveness of the approach (no need of controller's head tracking system and see-through displays) has led the Consortium to select and implement the simplified AR approach.
It must be mentioned that, despite the simplicity of such an approach, the AR system developed in the AD4 project could be easily adapted to specific operational needs of airdrome control. Presence of occlusions in some areas of the airdrome is a possible case of use. In this situation video-cameras are commonly used to frame the occluded airdrome area. In presence of visibility problems, due to night or bad weather conditions, the simplified AR approach can be a solution.
Furthermore it must be noticed that tiled displays, where images coming from different cameras are merged to provide a higher field-of-view, can be easily coupled with our simplified approach in the use of Augmented Reality techniques.
The AR system is made up of a set of software components running on a standard PC (desktop or laptop) and devoted to integration of heterogeneous data coming from different sources, such as video from camera, position tracks of aircraft and vehicles, airport geographic data, and to the actual augmented visualization at the Controller Working Position (CWP). This part of the system is also referred to as AR CWP.

The AR CWP receives surveillance data (positions and identifications) of moving aircraft and/or vehicles in the airdrome from mobile terminals that are installed onboard the relevant aircraft/vehicles in the airport area.
Surveillance configured EGNOS/GPS receivers, installed on board of moving vehicles, provide the position data. The necessary improved accuracy of GPS data and integrity of the Signal in Space are provided by the EGNOS augmentation system.
A communication infrastructure is responsible for managing the connection between the mobile terminals and the AR CWP. Such infrastructure is based on NEXT's XInfo™ infrastructure. XInfo provides all the necessary infrastructural functions, such as reliable communication between the terminals and the AD4 AR–based system, terminal secure authentication etc, to propagate the augmented satellite data within the system.

Video data are received from a camera (potentially even more than one) installed in the control tower, near the AR CWP, and looking at a selected part of the airdrome, thus having fixed position, orientation and field of view.
In the AR CWP, video data are merged with synthetic ones in order to generate and display the augmented scene. The augmented scene is actually displayed on a standard flat screen.
The figure below shows a very high level overview of the system architecture.

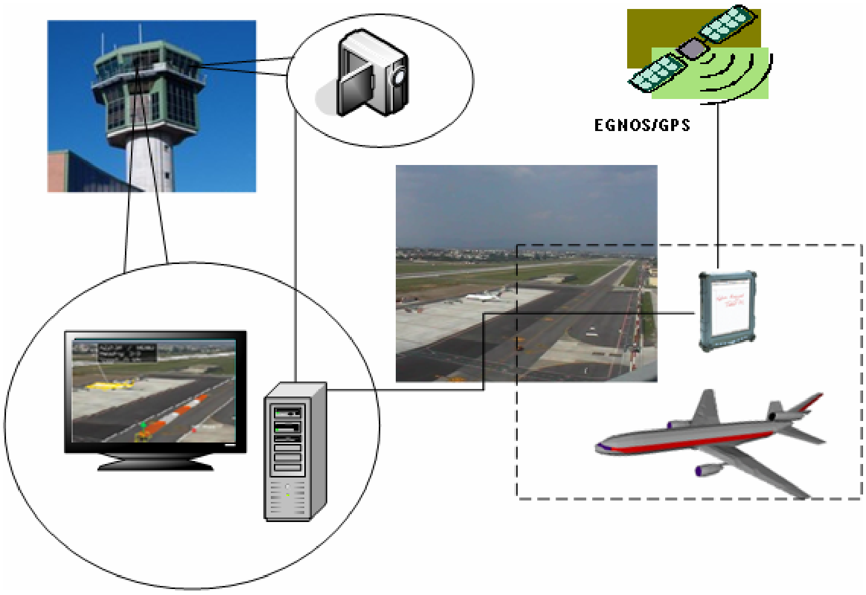


Figure 4: The AR demonstrator: system overview

The AR Display is composed of one monitor where the AR view, made up of the real airport view merged with the 3D representation of some of its elements, is presented in the AR main window.

Figure 5: Overview of the AR display

The Future Flight concepts

Future Flight Concepts demonstrators (3D Bubble, Distortion Lens, PIP) have been developed to investigate and experiment on possible combined 2D/3D displays for air traffic control.
Combination displays are those that present the viewer both a 2D and a 3D image of the same object in the same field of view. These displays are intended to support typical visual perception tasks in air traffic control. These tasks include the detection of separation between aircraft in the vertical plane, and the projection of the future positions of all the aircraft under control.

The **Bubble 3D** prototype has been created to experience some methods for being able to visualize three-dimensional information, without modify completely the classical radar visualization or, at least perform a smooth context switching between different visualizations.
The 3D visualization is represented as a projection, with a different perspective, of the 2D visualization. The same information presented in a classical radar are displayed in the same way. Aircraft are visualized as point with an information label, the trajectories laying on the plane as well all the other information.
A three dimensional bubble appear in the screen and permit to arise all the object that are inside it and provide additional 3D information. The aircraft inside the bubble change their shape becoming a pyramidal wedges with the apex pointing in the direction of speed, the trajectory are visualized in three dimension. The developed prototype has a lot of customization implemented in order to fit better and try to test several different configuration.
Different bubble models (disk, semi-sphere, sphere, cone (with infinite length)) are provided and for each model the user can change some parameters (height, size).
The type of 3D perspective is fully customizable: the user can change the view using the mouse and navigate with the help of keyboard. In this manner controllers can choose the best view to control better the flights.

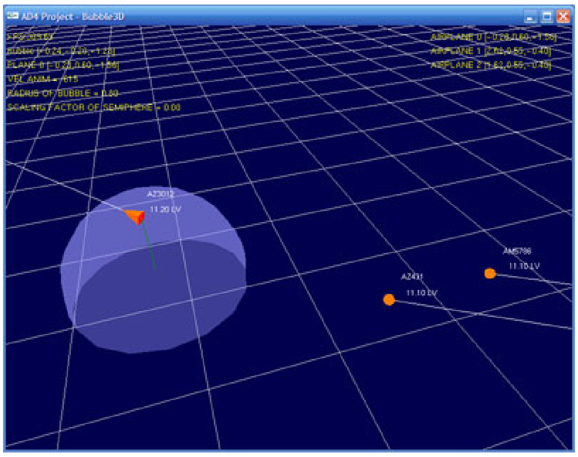


Figure 6: Bubble 3D display overview

The **Distortion Lens Display** is composed of one monitor where a 2D view “from above” of a portion of simulated airspace is presented to the user (controller), in the main Distortion Lens window. The window can either occupy the full screen area or a part of it.

The Distortion Lens main feature consists in the ability to display a localized 3D view, corresponding to a selected sub-region of the whole 2D view, within the overall 2D “radar-like” view of the airspace itself, the two views (2D and 3D) being merged together in a single visualization solution.

Such integrated display preserves continuity between those parts of the virtual scene that fall in the 2D view and those which fall into the 3D view (trajectories in particular).

The integrated visualization is obtained by implementing a transition zone at the interface between the two areas, where the 2D visualization is smoothly and progressively transformed into a 3D one, as shown in figure below.

The area to be displayed within the 3D view corresponds to a rectangular region and is interactively selected by the user. The current selected area is highlighted by rendering it in light grey color, while the 2D background is black (or dark grey).

The **Picture within a Picture (PIP) Display** is a presentation of a variety of different visualization/interaction styles for a domain specific application viz. the simulation of an air traffic control radar display. It presents (simulated) aircraft moving in the viewing window, and allows the user to visualize the aircraft in three main modes. Firstly a 2D only representation, secondly a 3D only representation and finally an integrated 2D/3D view using a specialised Picture-in-Picture (PIP) display on demand. The different visualization/interaction styles are available to evaluate the effectiveness of the different representations with regard to specific tasks in the ATC domain, primarily vertical separations. In addition to the major modes described here, additional HMI component are also deployed these include presentation of forward trajectory vector, drop lines to the ground, 3D temporal curtains, destination vector drawing and presentation of lines linking aircraft together.

When interacting with the “Picture in a Picture” HMI, user selects a relevant area in the 2D view, which then rotates downwards, thus turning in a localized 3D view (Fig. 52). The rotation is smooth to avoid the user to get lost. The localized view represents aircraft at their current flight levels. The “temporal curtain” represents their future positions and flight path profile.

The Picture within a Picture (PIP) Display was developed as an alternative innovative 3D-in-2D interface, in response to the display presentation needs for ATC controllers identified in the AD4 Operational Concept Report.

1.3 THE EXPERIMENTAL ACTIVITIES

A series of experimental activities have been conducted to assess and demonstrate the portfolio of results achieved by the AD4 project to controllers and technical specialists:

- **Evaluations** have been conducted to establish the "fitness for purpose" of the AD4 operational concept.
  The AD4 Operational Concept consists in deploying 4D (Space plus Time) displays in order to enhance the presentation of the spatial-temporal information necessary for controller's job.
  Following MAEVA methodology, high level evaluation objectives have been identified and mapped to a set of low level objectives with associated hypothesis, metrics and data collection methods. In particular safety (mapped to both workload and situation awareness low level objectives), usability and acceptability have been identified as high level objectives of the AD4 evaluation activities.
  Real-time simulation has been selected as the most appropriate evaluation technique and ATC simulation platforms, like ESCAPE/ACE and ATRES, have been chosen to feed the system with simulated operational data (i.e. radar tracks, flight plans) and events (i.e. conflicts).

- **Demonstrations** have been conducted to demonstrate results/capabilities achieved in all the fields covered by the AD4 project (4DHMI in both APPROACH and AIRPORT ENVIRONMENT control, Augmented Reality in the AIRPORT ENVIRONMENT, Security, MDA and development life-cycle) to controllers and technical specialists as well as to a broader audience at dissemination events

- **Proves of concepts** have been conducted to assess ideas for future developments. Experiments on combined 2D/3D displays for ATC (3D Bubble, Distortion Lens, Picture in Picture) and Augmented Reality Evaluations/Demonstrations are the most relevant proves of concepts performed.

<u>Execution of Demonstrators Test with Human in the Loop for the APPROACH 4DHMI</u>
The evaluation took place at SICTA simulation room in Naples from 25th to 27th November 2006.
Four experienced air traffic controllers from the Naples Approach Sector were recruited to participate in the evaluation. Their experience included all of the ACT phases, and years of activity ranged between 10 years (1 subject) and 20 years (3 subjects).

The setting for the validation included:

- one measured sector, which is Naples Approach, including Naples Airport (LIRN) Airport and the military areas R62 and R63;
- three feed sectors, which are:
  - TS/US sector, resulting by the combination of US and TS Rome Area Control Centres;
  - Naples Tower
  - Brindisi ACC.

For the simulation, three different scenarios were used. All scenarios lasted about 30 minutes and were conducted in a human in the loop simulation, i.e. controllers could assign instructions and clearance to traffic being in frequency with pseudo pilots, as well as controllers of other traffics.
The scenarios were collected during interviews with operational controllers in order to represent real traffic situations that might occur in Naples approach sector. The *Validation Plan* for Approach control available in the *D30_Evaluation and Assessment Report* document describes the rationale behind the validation scenarios and the link between these and the initial scenarios emerging from the early data collection in Rome, which are reported in the *D12_Operational Concept Report,* from which user requirements have extracted.

ID	Scenario Theme	Critical Event
1	Approach	Intruder aircraft breaks a landing sequence
2	Holding Stack	Emergency demand a quick descent of an aircraft engaged at the top level of busy holding stack
3	Final Approach Fix	Low visibility, one runway in use in one direction only. Coordination of landing and departures in opposite directions is required

Table 1. List of traffic scenarios used in the AD4 validation

Two adjacent working positions - planner and executive - were available in the simulation room. The subjects operate at the executive working position. The planner was operated by personnel from the Validation Team, as difference between this HMI and real HMI would have required extra training for controllers.
Both executive and planner used a 2D Barco LCD display placed in front of them as their primary display. This was operated by a mouse as in real setting. In addition to that the 3D/4D AD4 system was available on the executive working position. It consisted of two displays:

(i) a 3D radar display: this was the display that showed the information which was under evaluation. It usually displayed a 3D view of a portion of the sector.

(ii) a 2D navigation display: this monitor offered a top view of the sector upon which the controller could navigate and change the point of view of the 3D display.

The two AD4 displays were operated by an additional mouse which allowed firstly selecting an interesting portion of the airspace where to place the 3D camera. This was possible when the mouse was placed over the navigation display. Secondly the same input device allowed to navigate the camera back/forward, up/down when operated on the 3D display.

Controllers were also provided with a headset that enabled them to communicate with pseudo-pilots and adjacent sectors. There were no other sources of flight information such as paper flight strips available to the participants. Finally, an input device made of five buttons was placed in front of the controller. This allowed the collection of workload subjective measures.

The 2D radar display was placed in front of the controller as in a real life setting and 3D AD4 display under test was placed to the left of the executive working position, rotated at about 45 degrees to the controller line of sight. The navigation display was placed on the left of the 3D monitor rotated of about 90 degree from the controller line of sight. Overall this resulted in a Side by Side configuration, where users must search information across different display. Figures below show the display disposition.

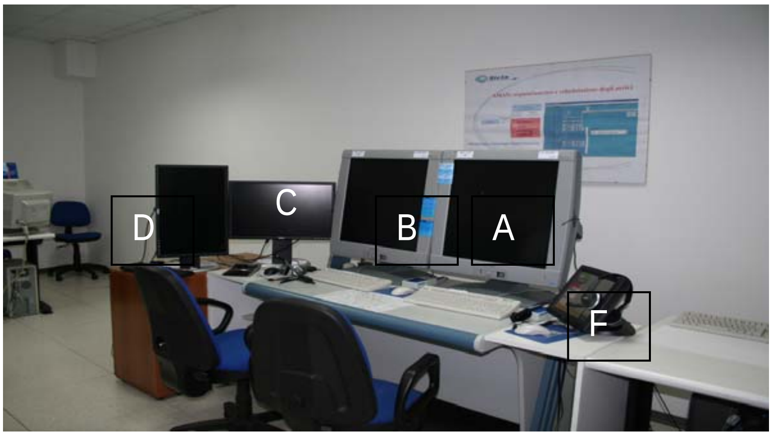


Figure 7. The executive and planner working position used during the simulation. The display were as follow: planner 2D radar display (A), executive 2D radar display (B), executive 3D radar display (C), and finally executive navigation display (D), see text for description. In front of the controller (F) was also placed the input device for the Instantaneous Self Assessment Tool for workload measurement.

Figure 8: The experimental working position in operation, with the executive sitting on the left, and the planner on the right.

<u>Execution of Demonstrators Test with Human in the Loop for the AIRPORT 4DHMI</u>

The evaluation took place at SICTA simulation room in Naples from 24th to 25th Jannuary 2007.

Four experienced air traffic controllers from Naples Tower Control were recruited to participate in the evaluation. Their experience included all of the ACT phases, and years of activity ranged between 10 years (1 subject) and 20 years (3 subjects).

The setting for the validation included Naples Tower Control.

For the simulation, three different scenarios were used. All scenarios lasted about 30 minutes and were conducted in a human in the loop simulation, i.e. controllers could assign instructions and clearance to traffic being in frequency with pseudo pilots, as well as controllers of other traffics.

Scenario design was based on (i) general classes of critical events – ref. AD4*_D12_Operational Concept Report_Vol2: Tower Control* – and (ii) the contribution from ENAV air traffic controllers. This background made possible to reproduce unexpected traffic events that might occur in Naples Tower Control where the novel display could potentially ease the controllers' task. The *Validation_Plan* for Tower Control, available in the *D30_Evaluation and Assessment Report,* describes the tower scenarios presented during the simulation.

Table 2. List of traffic scenarios used in the AD4 tower validation

ID	Scenario Theme	Critical Event
1	Single Runway Incursion	An unauthorized aircraft enters the runway
2	Double runway Incursion	Two aircraft enters the runway at opposite ends, due to misunderstanding of take off clearance
3	Loss of separation between incoming and departing aircraft	An aircraft aligned and ready to take cannot move due to a broken undercarriage. While incoming traffic has been authorized to land.

Of the four Tower Control Working position – Planner, Ground, Coordinator, Tower – the simulation replicated the Tower Controller working position. A pseudo pilots was also available and he was sitting in a different room.

The 3D/4D AD4 system consisted of two displays:

(iii) a 3D radar display, which showed a 3D view of the airport

(iv) a 2D display, which showed:

a. An Approach Window, offered a top view of the aerodrome that enabled the controller to monitor the approaching traffics, as in a real working position.

b. A Navigation Window: a small top view of the airport; this enabled the controller to understand where the camera point of view was located and where it was pointing at in relation to the airport, and to change it.

The two AD4 displays were operated by a 3D mouse which allowed firstly selecting an interesting portion of the airspace where to place the 3D camera. This was possible when the mouse was placed over the navigation display. Secondly the same input device allowed to navigate the camera back/forward, up/down when operated on the 3D display. Finally, Controllers were also provided with a headset that enabled them to communicate with the pseudo-pilot. There were no other sources of flight information such as paper flight strips available to the participants.

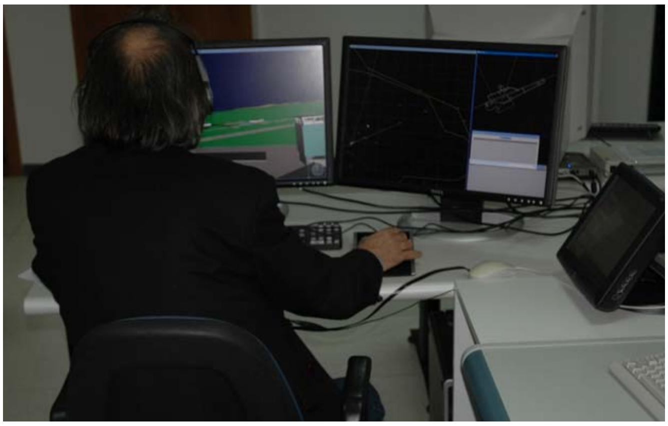


Figure 9. The Simulated working position in operation.

The 3D display was placed in front of the controller, and the navigation display was placed to the right of the controller, rotated at about 20 degrees to the controller line of sight. Overall this resulted in a Side by Side configuration, where users must search information across different display. Figures and show the display disposition.

Execution of Demonstrators Test for the Augmented Reality HMI in the AIRPORT environment

The activities took place at Naples Capodichino Airport the 22nd and 23rd of February 2007. In that occasion, the AR system was presented to two experienced air traffic controllers during a set of real traffic situations occurring in the airport.

The present study represents the second test of the AD4 tower HMI. The criteria to conduct the validation were set during the AD4 meeting carried out in London the 12th, 13th October 2006 at Middlesex University. In that occasion due to available resources (mainly a limited number of controllers) and existing constraints, it was decided to carry out a qualitative assessment of the AR HMI. Thus, it has not been refereed to hypotheses in any experimental sense, as the qualitative results would not allow any statistical hypotheses test.

Aim of this evaluation was to get a feedback from controllers about the use of AR visualization in the Tower Environment; the focus of the evaluation was:

- whether and why AR is valuable for tower controllers
- how AR affects situational awareness;
- what are the relevant usability issues implied in operating the AR HMI
- what is the acceptability of the AR system from operative personal, i.e. to what extent real tower traffic controllers would accept to work with such a system.

Two experienced air traffic controllers from Naples Tower Control participated in the evaluation.
However, due to safety reasons, i.e. in order to avoid interference with their work, the controllers were only ask to observe the visualization capabilities of the AR system and to express their considerations on it; therefore, no direct interaction with the system was required from controllers.

The setting for the validation included Naples Tower Control.

The "identification" scenario was used as a baseline for running the demonstrations. This scenario is suitable for demonstrating the main capabilities of the AR system in terms, such as the ability to provide identification labels linked to the real airplanes/vehicles and to contextually provide additional information related to a specific aircraft (e.g. speed, direction, etc.).

The AR controller working position consisted in a standard laptop PC, displaying the AR HMI on a standard monitor.

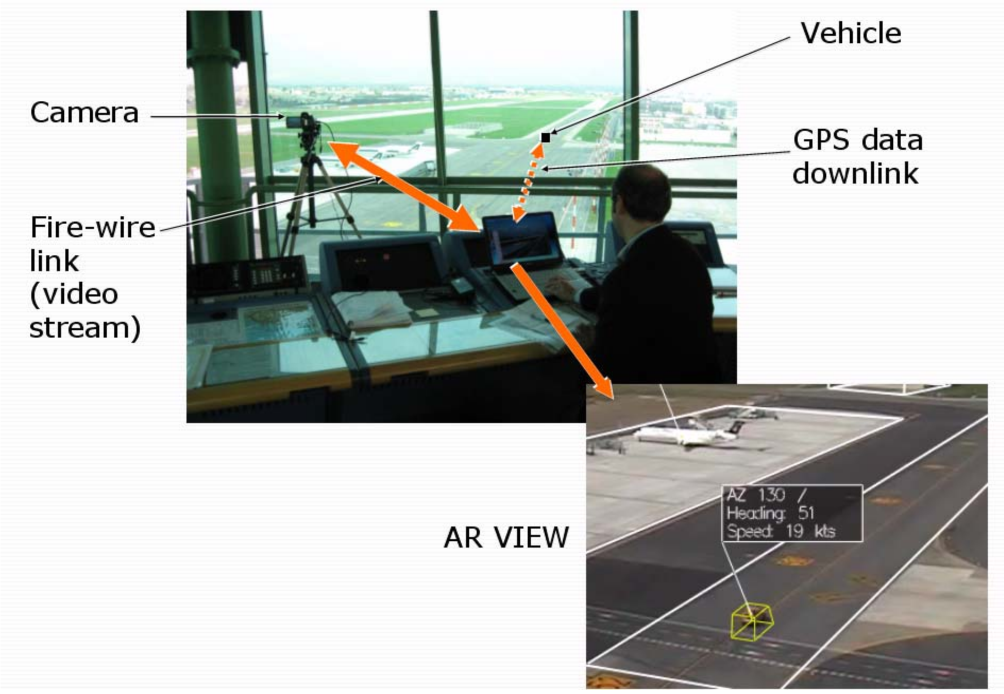
The AR AD4 system consisted of the following hardware components:

(v) an AR workstation, consisting in a laptop PC, showing the AR HMI visualization window as well as other GUI control panels for the control of the visual settings and the running system;

(vi) a Digital Video Camera installed at a fixed position inside the control tower, looking at R24 threshold (North-East direction) through the tower windows; the camera was connected to the AR workstation via a Firewire connection cable;

(vii) an experimental vehicle authorized to run on the airdrome surface, according to instructions provided by the ground and tower controllers;

(viii) an EGNOS-enabled GPS receiver installed onboard the experimental vehicle, used for position, heading and speed tracking;
(ix) a wireless + ADSL network connection from the GPS receiver to the AR workstation.



1.4 THE DISSEMINATION ACTIVITIES

Exploitation and Dissemination activities are carefully planned for the AD4 project. In particular activities such as:

- Build a traditional Website, helping to distribute up-do-date information both to users as well as to the Commission
- Held two different Workshops to disseminate, publish and invite relevant actors of the field.
- Organise live-demonstrations to disseminate the AD4 technology
- Publication of papers over the Internet, publication through traditionally paper-based channels, presentation of the results to appropriate for a, such as R&D Centres and Academic communities. Preparation of the Technological and implementation Plan.

Over the two years of the AD4 project, members of the consortium have published 20 articles in a variety of scientific and industry outlets, developed and maintained a project website; organised and participated in three AD4 specific workshops, exhibited and demonstrated the AD4 D3 system in a number of trade conferences and industry-specific events; and have also published a contribution to the OMG Standards on CORBA Components.

The publications can be broadly grouped into the following themes that parallel the areas of work undertaken by the AD4 Consortium. The publications generally describe the key innovative outcomes of the project, including the real-time integration of the AD4 platform with distributed ATC simulation platforms, the MDA tool chain, the Open PMF-based secure middleware, the augmented reality applications in the control tower, and the Future Flight Concepts.

A project website was developed and maintained by the project coordinator, and may be accessed at http://www.ad4-project.com/. This website has two main sections: a public site presenting brief information about the project, and a private, password-protected section containing all AD4 official reports and relevant resources. Members of the consortium have also prepared videos for demonstrating various unique innovations that have emerged from the project, such as the use of augmented reality in the airport control tower. In addition, the AD4 project was featured on the EURONEWS channel in both English and Italian. A copy of that broadcast is also available at the project website. A number of posters were also prepared for presentation at conferences and workshops and are available on the website.

Partners of the Consortium have also hosted exhibition stands at various conferences and trade-shows. At these exhibition stands, the system was presented and demonstrated. Attendees at these events could also interact with the system to experience the AD4 visualisation and interaction. Specifically the exhibitions in the second part of the project are listed below.

- CER 2005, Brussels, 14-15 November 2005
- EEC INO Workshop, Bretigny-Sur-Orge, Paris, 6-8 December 2005
- Aeronautics Days 2006, Vienna, 19-21 June 2006
- EEC INO Workshop, Bretigny-Sur-Orge, Paris, 5-7 December 2006
- ATC Maastricht, Maastricht, 13-15 February 2007

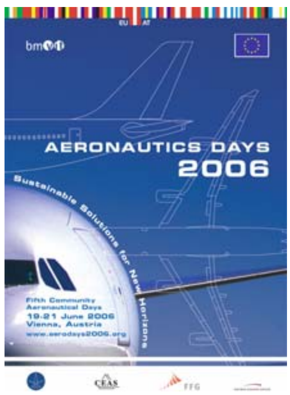
AD4 attended the Communicating **European Research 2005** (CER 2005) that took place in Brussels on 14-15 November 2005. CER is the most important event dedicated to the dissemination of the European Research. Throughout the event, latest research results and current scientific activities were presented to the media in press conferences and media briefings. A huge exhibition featured selected research initiatives as well as the communication strategies of research organizations. After a call for participation, AD4 was selected to participate among a huge set of competing projects, demonstrating the value of the first year results.

AD4 was hosted in the EC projects section of the exhibition with a stand dedicated to it and equipped with a demonstration system and posters illustrating the project. AD4 kept the attention of the visitors demonstrating its capabilities of visualizing and navigating a 3D representation of the airspace. Positive feedback came from people involved in the ATM field. Furthermore we were interviewed by the **EuroNews** satellite television (http://www.euronews.net) as well as by other media channels. A video clip with the interview is available in the Hi-Tech section of the EuroNews web site at the following address http://www.euronews.net/create_html.php?lng=1&page=hitech

AD4 was also present at the **4th EUROCONTROL Innovative Research Workshop & Exhibition** that took place on December 6-8, 2005, at the EUROCONTROL Experimental Centre, Bretigny-sur-Orge, France. The workshop is becoming a major and recognized event in Europe. In 2004, more than 150 external visitors, representing various sectors of the air transport industry in over 20 nations, attended the two-day workshop. The AD4 project was presented during the conference and at the exhibition area.

A paper illustrating the main characteristics of the AD4 project was submitted to be inserted into the Workshop proceedings and presented during the conference. The INO workshop gave the AD4 Consortium the opportunity to present concepts and ideas of the AD4 project to people involved in research activities in the ATM field. A prototype of the system was demonstrated in the exhibition area of the workshop, receiving a very interesting feedback from the visitors of the stand.

AD4 was present at the **Aeronautics Days 2006** event that took place on June 19 – 21, 2006, in Vienna, Austria (http://www.aerodays2006.org).



A prototype of the system was demonstrated in the exhibition area, receiving a very positive feedback from the visitors of the stand. The stand was composed of one graphical workstation equipped with 24 inches aspect monitors to display 3D representations of the Approach and Airdrome sectors. A connection to a server machine, equipped with the ATRES simulation platform, provided air traffic samples and flights data.

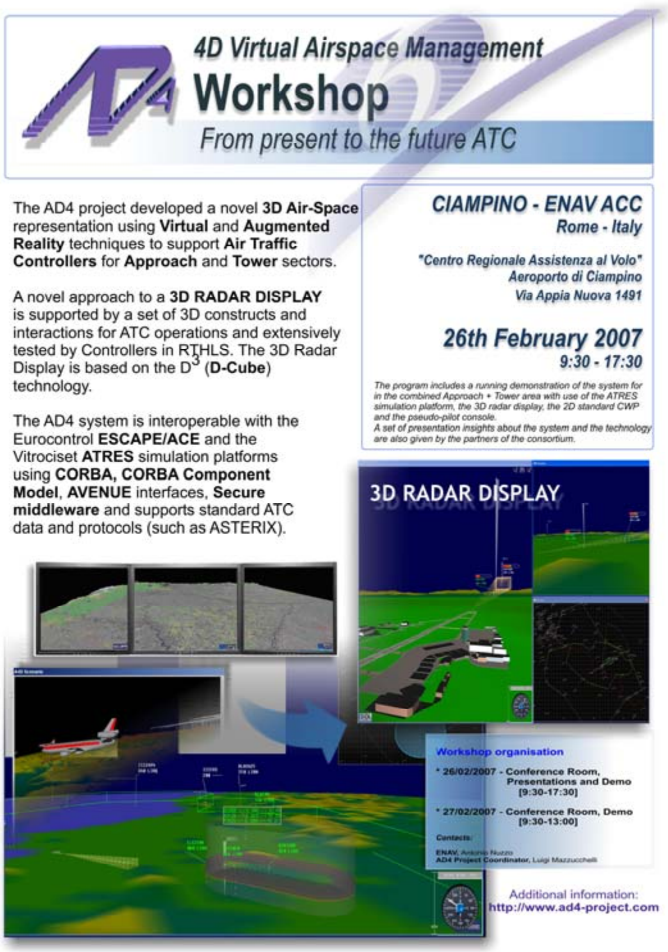
Visual impact of the presentation was emphasised by using a wider field-of-view allowed by the use of two 24' wide aspect monitors.

A **parallel session** was dedicate to the AD4 project during the **5th EUROCONTROL Innovative Research Workshop & Exhibition**, held at the EEC in Bretigny-Sur-Orge, just outside Paris, on 5 Dec 2006. Each partner in the Consortium presented (either individually or jointly) papers that reported on key aspects and achievements of their work. These papers were published in the EEC INO Workshop Proceedings and have been referred to earlier under section on 'Publications'. For convenience, the papers were also compiled separately as "Visualisation and Distributed System Technologies: The AD4 Approach. Innovative Research 2006, Parallel Event". In addition to members of the consortium attending and presenting at this parallel workshop at the EEC, the parallel event also attracted participation from researchers at the University of Linkoping, the EEC itself, and Mitre Corporation and Emory Riddle University in the US.

AD4 was also hosted at the exhibition of the EEC INO Workshop that took place on December 5-7, 2006 in Bretigny-Sur-Orge, Paris.
The following demonstrators were presented

- The AD4 integrated system for 3D/4D visualization of Approach and Airport Environment scenarios
- The Augmented Reality Proof of Concept in the Airport Environment
- The Future Flight Concepts in the Integration of 2D/3D Displays
- The MDA Tool Chain and Security demonstrators

The **first workshop** of the AD4 project, promoted to involve major players of the field of ATM and key users, to endorse the activities of the project, helping the dissemination towards the user community and the public awareness was appointed at Rome CRAV of Ciampino the 5th of October 2005. Some of the registered attendees at the workshop were external to the Consortium and included representatives from the Italian Space Agency and the EUROCONTROL Experimental Centre in Paris. In fact, the Workshop has also led to opportunities to meet with EUROCONTROL personnel, discussing AD4 in relation to research into 3D ATC interfaces at University of Linkoping, and an invitation to attend the EUROCONTROL Innovation Workshop in December 2005.
A real mock-up of the targeted AD4 system, together with the explanation of relevant concepts by means of oral presentations for each relevant activity and the support of posters, was presented at the workshop.
It was attended by a number of air traffic controllers from Ciampino ACC, as they became available and the collection of impressions from participants and controllers were used to improve the results of the key activities and in particular to stimulate feedback from controllers. Specifically, a small feedback session on the AD4 user interface was also held with five off-duty air traffic controllers from Ciampino ACC.



The **final workshop** of the AD4 project, promoted to disseminate result of the project to major players of ATM field and key users, took place at the ENAV Area Control Centre (ACC) at Ciampino on 26th and 27th February 2007. This workshop followed an early one, which took place during October 2005, and its purpose was publicised and demonstrate the work done, the results achieved and the learning resulting from the two years project. It also possible to say that this represented a formal event which marked the end of the project.

NEXT with the support by ENAV organised the workshop. The themes were developed and each partner contributed a presentation or part of a presentation. Invites were sent to key personnel in the domain and the conference facilities booked at the CRAV (Centro Regionale Assistenza al Volo) centre at Ciampino Airport in Italy. The presentations were viewed and standardised, and each partner contributed parts as required. The workshop hall was split into two parts the presentation room and a demonstration room for the D-Cube demonstration by NEXT. The demonstrator was staffed by NEXT personnel for the duration of the workshop

1.5 AD4 DELIVERABLES

Del No.	*Deliverable Title*	*WP no.*	*Dissemination Level*	*Summary*
1	**Project Management Plan**	1	CO	The document details Managerial processes to be used to achieve project objectives within the scope, time and budget of the contract AD4. Specific definitions of technical processes are also given, together with the summary of milestones, deliverables, work-packages and responsibilities for the partners.
2	**Periodic Management Report**	1	RE	It contains the summary of the technical achievements, work-packages tasks and management summary for the first year of the project. The present document, currently in version 2.0, is showing the progress of the project for the second reporting period July-December 2005. It constitutes an update of the first reporting period report and highlights the current status of the project, at technical and managerial level. It encloses a summary of the activities, status of deliverable and first year assessment of results.
3	**Quality Assurance Plan**	1	CO	The Quality Assurance Plan (QAP) defines the activities performed to provide assurance that the System-related items delivered conform to the established technical requirements. The QAP also describes how the project will be audited to ensure that the policies, standards, practices, procedures, and processes applicable to the project are followed.
4	**Configuration Management Plan**	1	CO	The present document is the Configuration Management Plan (CMP) for the development of the AD4 Project. The purpose of this plan is to describe the Configuration Management (CM) activities that will be performed during the AD4 design, development, implementation, testing, integration, validation, qualification, acceptance, delivery and maintenance activities.
5	**Project Web site**	6	PU/RE	The Project Web site contains information on the project. It is organized in public and restricted sections.
6	**Project Leaflets**	1	PU	The project leaflets illustrate the most relevant activities performed and results achieved by the AD4 Project

7	**Project Presentation**	1	PU	The Project Presentation intends to present the most relevant aspects of the project
8	**Final Plan for using and disseminating the knowledge**	1	RE	This deliverable contain the final plan for using and disseminating the knowledge established and followed by the AD4 Consortium
9	**Exploitation and Dissemination Plan**	6	PP/PU	This document intends to illustrate the organization and plan of the AD4 consortium to disseminate and exploit AD4 project results
10	**Final Activity Report**[1]	1	PU	This document constitutes the Final Activity Report of the AD4 project.
11	**Report on raising public participation and awareness**	1	PP	This report expresses the way the AD4 Consortium intends to raise public participation and awareness of the project results, of the technological as well as of the human aspects that will result from the project activities.
12	**Operational Concepts Report**	2	PU	This report presents the AD4 Operational Concept Report for the Approach and Tower Control phases of ATC control. For each of these phases the main finding are reported, they are: (i) the representation design requirements in terms of 4D visualization and interaction needs, (ii) the operational scenarios on which these requirements are based, and (iii) recommendations for the way in which the 4D representations can be delivered so as to respect collaborative practices, enabling the maintenance of shared awareness between controllers, the ability to support 4D visualization within the current PPI radar displays (Approach Control), and the avoidance of overly literal translation of physical world features into the 4D HMI design.
13	**Market Analysis and Competitive systems study**	6	PU	The main goal of this document is to provide a detailed study of the ATM market from the point of ATS providers' view and industrial companies. Moreover the main industries operating in ATM world will be considered and their approach to 3D HMI (Human Machine Interface) will be studied and compared to remark differences and common aspects.
14	**State-of-Art review Report**	2	PU	State of Art review report
15	**Standards assessment Report**	2	PU	It describes the current and emerging Standards in ATM.
16	**Next generation 4DHMI concepts**	2	PU/RE	This document aims to explore techniques, concepts and visual metaphors that could be adopted for the design of ATM 4D visual interfaces. Virtual Reality techniques as well as possible 3D visual characteristics of the objects identified in

[1] Includes a publishable D8

				the analysis of the operational scenarios are illustrated as well.
17	**Model Driven aspects**	2	PU/RE	This deliverable explains Model Driven Software Development (MDSD) concepts and approaches (e.g. MDA), and describes how MDSD can contribute to the development of software systems in the ATM domain in the AD4 project context. It also specifies the AD4 tool chain for model driven development of AD4 platform.
18	**Prototyping Process Report**	2	PU	This document illustrates the prototyping process that will be adopted by the AD4 consortium and how prototyping approaches and activities will influence the software development life-cycle. It intends also to present a roadmap to the realization of the so called Mock-up, an early executable prototype aimed to get usability feedback, and of the final AD4 prototype.
19	**System Requirements**	3	PU/RE	The document lists the system requirements. These requirements then form the basis of the architectural design of the AD4 system.
20	**Architectural Design Document (preliminary and final)**	3	PU/RE	This document illustrates the architecture of the AD4 system highlighting the fundamental components, their interfaces and the interrelationships among them
21	**Life-Cycle Development and Engineering Process Report**	3	PU	This deliverable introduces relevant software development lifecycles that are used as a basis to define the AD4 system life cycle. A definition of the AD4 life cycle is also included.
22	**Simulation and Demonstration Environment Report**	3	PU/RE	This document intends to treat the following subjects: - Overview of all demonstrators (both ACE based and ATRES based) - Description of simulation environment (exercises, data, controllers, metrics) - Demonstration report
23	**System Integration and Test Plan**	3	PU/RE	This document illustrates the system integration and test plan adopted in the AD4 project.
26	**System Integration and Test Report**	3	PU/RE	This document reports the results of testing activities conducted in the course of the AD4 project.
25	**Core Components**	4	CO	This document lists the components being part of the AD4 system, the ones developed in the course of the project as well as the ones belonging to ATC simulation platforms AD4 interoperates with
26	**Airport 4DHMI Specifications**	4	PU/RE	This document presents a series of specifications of the APPROACH Control Center 4DHMI, aiming to define Human Machine Interfaces for visualizing and interacting with 4D data in the APPROACH sector.

27	**Tower 4DHMI Specifications**	4	PU/RE	This document presents a series of specifications of the TOWER 4DHMI, aiming to define Human Machine Interfaces for visualizing and interacting with 4D data in the TOWER sector.
28	**Demonstrator**	5	PU/CO	This document illustrates all the demonstrators developed in the course of the AD4 project
29	**Safety Assessment Report**	5	PU	This report provides Safety Assessment for the AD4 activities.
30	**Evaluation and Assessment Report**	6	PU	This document is aimed to describe activities carried out for the evaluation and assessment of the results originated from the demonstrator activities. Therefore, main goal were to measure the correspondence of the AD4 new operational concepts in relation to the user requirements, defined in AD4 project previous phases, in an experimental environment.
31	**Dissemination Reports**	6	PU	This report provides details of publications, presentations and other public provision of information about the AD4 project by its Partners.
32	**Workshop results report**	6	PU	This document provides a dissemination of the results of the AD4 Workshops held in Ciampino Area Control Centre in October 2005 and February 2007. It summarizes the presentations and includes screen shots of the posters used at the workshop. It also serves as an administrative record of details such as attendees, and workshop programme.

Summary of the Project, Contacts and Consortium Information

Title:	**4D Virtual Airspace management System**
Acronym:	AD4
Contract Nr.:	AST4-CT-2005-12328
Total Cost:	3.502.926 €
EU Contribution:	1.929.978 €
Starting Date:	01/01/2005
Duration:	26 months
Web-site	http://www.ad4-project.com
Coordinator:	Dr. Luigi Mazzucchelli
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SICTA SpA	I
Fraunhofer Fokus – Institute for Communication Systems	D
Object Security	UK
Digital Video SpA	I
European Software Insitute - ESI	E
Space Applications SA	B

2 PROJECT EXECUTION

2.1 BACKGROUND

The management of air traffic across the wide areas used in international routes is a growing problem with the increasing numbers of passengers and flights in operation while the systems used for ATM are adopting new technologies quite slowly and the modern controller uses working environments similar to that in use for more than 30 years.
Furthermore future scenarios do not simply involve an increase in air traffic; in addition new forms of co-operation and co-ordination are expected to emerge. New IT technologies and platforms afford more data to be available to many of those who run the whole ATM system. As the human factors literature suggests, the availability of more data implies new forms of task distribution and thus new co-operative strategies have to be anticipated. This implies a paradigm change when designing for new technological support.

Air Traffic Management is partly a four dimensional problem (three spatial dimensions + time) where aircraft geographical position, altitude, speed and foreseen trajectories, as well as terrain elevation and meteorological data, must be monitored by air traffic controllers while controlling aircraft along their route. Despite this fact and the long discussions about its possible benefits, no extensive use of 3D technologies has been made to date:

- Human Machine Interfaces employed by controllers use flat, 2D radar pictures with classical 2D mouse and button-based controls.
- Pilots may have no traffic displays at all, relying on charts and voice commands from controllers.
- Tower controllers use the windows of the tower as their main tool: they stand in the tower and need to have visual contact with the objects.

Furthermore the adoption of new technologies is significantly changing Air Traffic Management. Such changes are required to meet the expected growth in air traffic. Technologies such as the Global Navigation Satellite System (GNSS), Automatic Dependent Surveillance (ADS) communications and more sophisticated ATC software will provide some of these required improvements. These technologies will allow the automatic distribution of many types of data amongst pilots and controllers, reducing the need of voice communication among them but at the same time dramatically increasing the amount of information at disposal of controllers.
Moreover, the controller, to be able to handle the ever increasing traffic, will rely more and more on new features of automated systems made available by advanced ATM systems: automated tools have been progressively introduced to support operators in their decision making process.

The considerations above lead us to claim that the time for a new vision of HMI in the ATM and aeronautics domain has come. We think that the adoption of advanced human-computer interfaces, using intuitive and natural three dimensional displays similar to those developed in Virtual Reality systems, will allow controllers and pilots to reduce their cognitive load by improving situational awareness of the controlled air traffic situation.

A novel 4D approach, that we call D4 – to differentiate with the existing 4D ATM concept - creates new opportunities in the way the controller will visualize and interact with information: new ways of representing the information, while not necessarily decreasing workload, provide an opportunity to reduce existing knowledge gaps, supporting optimal decisions making (as demonstrated in recent works). In this context the AD4 project aims to build an innovative Virtual Air-Space representation for ATM system, providing a range of valuable benefits to support efficient control systems where 3D real time interaction with air traffic/airport space is accessible to the controllers.

2.2 PROJECT OBJECTIVES

The AD4 projects aims to explore the application and benefits of 3D (three dimensional) displays and interaction technologies with a view to determining the qualities required to produce an effective 3D information visualization environment for the air traffic controller. The implemented system, targeted at semi-immersive three-dimensional displays, makes use of VR techniques to provide an environment within which an air traffic controller can observe and monitor a large number of aircraft over a wide area, being kept aware of the many complex factors about their planned routes which may affect the future planning of the flight paths, and can use 3D interaction methods to select and re-route aircraft interactively as the data are updated in real time.

The targeted AD4 system has been designed and implemented in collaboration with experts in field of ATM systems, VR developers, Human factors and the Italian Agency for Air Navigation Services – ENAV, producing a specific demonstrator that encloses real interfaces and data coming from a Traffic Centre and Simulation environments and will be extensively evaluated by air traffic control personnel. The AD4 infrastructure shall enable to determine what benefits, in terms of enhanced understanding and clarity of perception, 3D displays and/or 3D representations in 2D displays, combined with enhanced information presentation, can provide to the controllers in Approach and Tower sectors. It is hoped [has highlighted in recent studies] that improvements in this area will permit more efficient and safe management of more aircraft over a wider airspace.

The key objective of the AD4 project is the enhancement of a 3D Virtual Reality system, called D3 (D-cube), for the real time visual representation and manipulation of data in the field of Air Traffic Management and Control, both in open space (particularly in the approach phase) as well as at Airport level. The D3 technology is capable to manage a real-time 3D visualization and navigation by means of the adoption of an open distributed infrastructure able to handle dynamical and scalable data elaboration and integration using auto-stereoscopic displays and 3D mouse devices.

To provide an effective test-bed for 3D VR interaction and visualization in air traffic management the consortium will be based on a robust, distributed and real-time system which can provide a controller with a 3D environment showing all of the aircraft active in the controller's particular region of interest and those whose routes will take them through it during their flight time. The flight information that will obtained should provide a complete set of inbound and outbound flights across a targeted airport and will include a range of different aircraft types and flight distances and shall be integrated with consolidated simulation platforms like Eurocontrol ESCAPE and Vitrociset ATRES.

Expected results

The AD4 project will construct different releases of the IT infrastructure integrating 3D technologies and ATM components, driven by Models by the use of OMG Model Driven Architectures and making use of Component Middleware (CORBA CCM). A final demonstrator will be hosted by a real ATM experimental centre and tested by air traffic controllers. Dissemination material will be published in a dedicated web site http://www.ad4-project.com to circulate important results in the relevant ATM communities.

The AD4 system will offer a "global vision" of the traffic flow that the controller has to organize, in order to balance it among two or more sectors. The 3D display will support the controller in the definition of such a balanced flow between the sectors, that is, the creation of segregation between flows, following a sort of "what if" strategy. At a visualization level, the 3D display will provide a wide overview of the air traffic and nicely support the process of balancing the workload among the sectors. The 3D immersive virtual reality displays care shown to be useful in allowing capturing a global image of the traffic and integrating in a single screen the 4 dimensions of the traffic problematic. The system will allow rapid and dynamic interaction with the scenes represented. Users could, as an example, zoom certain spots of traffic, perform rotations and translations of the scenes, interact with 3D/4D widgets and controls and have easy access to different point of views within the traffic flows. Seemingly, these wide interaction capabilities allow the dynamic appreciation of air traffic details, which are judged quite relevant for the activity. The sectors' traffic allocation is an interesting proposal and it also represents an original and unexplored application domain for 3D.

A command and control interface allows choosing the different layers of data that will be embedded in the Virtual Scenario, represented in 3D with the aid of immersive technologies. Incremental and fluid navigation, limited only by the complexity of the rendering area (mitigated by on-demand selected modification of the local objects in the scenario – the so-called immersion of singleton objects) is achieved. Within this environment we make use of 3D/4D interaction devices both to navigate in the scene and to select and manipulate flight information within the scene. The user's viewpoint is typically centred on a point of interest (initially located at the airport) but can be updated to centre on any position by simply pointing and clicking using a 3D mouse pointer. The same device will then be used to control rotation of the camera around the view centre in two degrees of freedom and zooming of the view. The presentation of relevant views of the approach as well as the tower sectors will help to demonstrate the feasibility of using scalable and performing novel approaches to the construction of system to support ATC operations.

2.3 SUMMARY OF THE PROJECT, CONTACTS AND CONSORTIUM INFORMATION

The AD4 project is planned of a duration of 24 months addressing the analysis of Operational Concepts and Human Factors, the engineering of the IT infrastructure and its core Components (4D HMIs, Middleware, Predictive and Applicative Components, Interfaces to external data e.g. Meteo and ATM system integration), the development the working Demonstrator for an operative context, the validation by the use of the MAEVA methodology and the assessment and exploitation of results.

The AD4 project is co-funded by the European Commission – DG-Research Aeronautics and Space and its consortium is composed of key players in the field. The AD4 system is designed and implemented in collaboration with experts in field of ATM systems, VR developers, Human factors and the Italian Agency for Air Navigation Services - ENAV.
The Consortium includes research as well as industrial partners committed to the acquisition and development of the advanced technological know-how required to address the project objectives and to the exploitation of the results achieved throughout a specific ATM infrastructure and a definite demonstrator. Final users and testers of the targeted ATM field are also key contributors to the project

development and assessment: they have produced specifications of real operational needs within their business cases and coordinated the final phase of testing and validation of the prototype.

The Coordinator of the project is the Italian NEXT-Ingegneria dei Sistemi SpA that acquired a significant experience in innovative technologies working in projects for the Italian Space Agency, the European Commission and the GALILEO Joint Undertaking.
Relevant contribution and support was made by the Italian Company for Air Navigation Services ENAV. Vitrociset (I), SICTA (I) that provided components and simulators for ATM context based on ATRES and ACE platforms respectively, Space Application Services (B) that contributed to the Visualisation technology and developed with NEXT the Augmented Reality Proof of Concept, Digital Video (I) that contributed to the Visualisation technology and ESI (E) that studied the Engineering Process; Fraunhofer Fokus (D), Object Security (UK) devoted their work to the MDA driven architectures, IT security and middleware. The University of Middlesex (UK) supported the Human factor analysis and the assessment of results.

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2.4 ACTIVITIES PERFORMED AND RESULTS ACHIEVED

The AD4 project, aiming to build a Virtual Air-Space representation for ATM systems, has faced several and different aspects, going from the development of secure middleware and distributed component-based IT infrastructure to application of 3D representations and Virtual/Augmented Reality techniques in the ATM domain, passing through the definition and implementation of a MDA (Model Driven Architecture) Tool Chain to support the AD4 development life-cycle.
The following picture illustrates the so-called AD4 Portfolio of achievements.

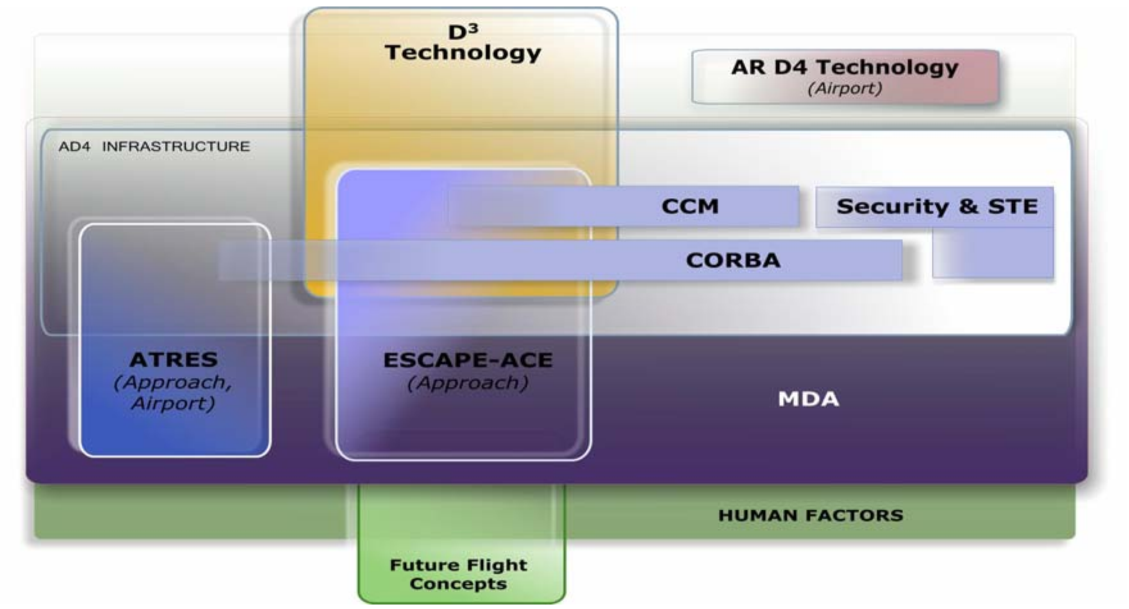


Figure 10. The AD4 Portfolio

<u>D^3 technology</u>

Virtual Reality (VR) approach in AD4 is based on the representation of visual elements within a purely synthetic 3D Virtual Environment that provides a 3D perspective display of airspace and airdrome.
The implementation of this 3D Virtual Environment is based on a 3D framework, called D^3 (D-cube) and developed by NEXT in a successful national research project. Such framework has been enhanced and properly tailored to the ATC domain during the AD4 project.
D^3 is a 3D Virtual Reality system for real time visual representation and manipulation of heterogeneous geo-referenced data such as DEM (terrain), meteorological data (clouds, pressure and wind fields), telemetry data, GNSS (satellite) and surveillance data (radar tracks). D^3 framework is capable of both 3D Visualisation and 3D Navigation.
The AD4 project has enhanced the D3 technology producing a 3D framework capable of supporting 3D representation and interaction in the air traffic domain.

<u>AD4 Infrastructure</u>

A strong emphasis has been placed on the definition and development of a robust and open IT infrastructure with the aim to build on it a distributed and component based 3D command and control system based on **secure middleware** (**CORBA** and **CCM**), supporting standard exchange formats (e.g. ASTERIX) and allowing the interoperation with ATC components and simulation platforms like the Eurocontrol ESCAPE and Vitrociset ATRES platforms.

CCM (CORBA Component Model) is one of the best platforms for developing large scale distributed systems. It is based on the mature CORBA middleware and adds some more advanced concepts. It simplifies the usage of some CORBA Services and enhances the Object Model of CORBA to include components.

Secure middleware in AD4 is composed of

- MICO, a CORBA ORB with improved support for security
- Qedo, a CORBA Component Model implementation with enhanced Quality of Service support
- OpenPMF, a security Policy Management Framework
- ObjectWall, an IOP Proxy for firewall traversal and domain boundary protection

Qedo is an open source tool suite that provides the development support, runtime environment, and deployment infrastructure for CORBA Components. The name Qedo stands for "Quality of Service enabled distributed Objects" and reflects the broad scope towards a component platform fulfilling the requirements of complex applications. The foundation of this is the CORBA Component Model specification defined by the OMG. Qedo is an implementation of this specification and offers a variety of extensions (e.g. QoS) to address specific needs of particular domains.
Qedo fully supports the component-based development cycle, namely: you can design, implement, compile, package, assemble, deploy, install, instantiate, configure, execute, and manage distributed CORBA component-based applications.
Qedo has been successfully improved in the framework of the AD4 project.

Secure Testing Environment (STE) has been successfully used to test the integration between the AD4 and ACE platforms in a remote way. STE is based on ObjectWall, an IOP Proxy for firewall traversal and domain boundary protection developed by Object Security in the course of the project.

The use of STE has allowed the SECURE access to SICTA's instance of ESCAPE/ACE, placed in Naples, from NEXT premises, placed in Rome.
By the use of STE it has been possible to get data remotely by the invocation of CORBA operations through the ObjectWall Domain Boundary Controller. Security policies were enforced and used in STE to control the access to the ESCAPE/ACE platform from outside the SICTA premises .

The AD4 infrastructure makes use of Distributed Computing with remote heterogeneous components providing data to be processed and/or displayed. In this context heterogeneity refers both to data (radar tracks, flight plans, weather and terrain data provided by different components running on different machines) and the way these data are provided (the use of TCP/IP protocol with exchange formats or Distribute Object Computing Middleware like CORBA are common approaches used in the ATC context).

Simulation platforms

D^3 platform has been successfully integrated with ATC simulation platforms. The result is the availability of two different integrated systems (D^3-ESCAPE and D^3-ATRES) ready to be used as a test-bed for current and future assessments on the use of 3D in the ATC context for both approach and airport phases of a flight.
Such integrated systems have been used in the final part of the project to conduct Real Time Human-in-the-Loop Simulations aimed to evaluate safety, usability and acceptability of the proposed AD4 4D Human Machine Interface.

Future Flight concepts

Future Flight Concepts demonstrators (3D Bubble, Distortion Lens, PIP) have been developed to investigate and experiment on possible combined 2D/3D displays for air traffic control.
Combination displays are those that present the viewer both a 2D and a 3D image of the same object in the same field of view. These displays are intended to support typical visual perception tasks in air traffic control. These tasks include the detection of separation between aircraft in the vertical plane, and the projection of the future positions of all the aircraft under control.

MDA (Model Driven Architecture)

The Model-Driven Architecture starts with the well-known and long established idea of separating the specification of the operation of a system from the details of the way that system uses the capabilities of its target platform. MDA uses models as central artefacts in the whole development cycle of computer systems; it provides a means for using models to direct the course of understanding, design, construction, deployment, operation, maintenance and modification.
The AD4 project has produced a MDA tool chain for the rapid model driven development of CCM based security-critical software systems based on SecureMiddleware. The tool chain supports a platform independent modelling of systems, there is no need to model, e.g., platform-specific data types, or to decide early in the development process which particular platform to use. By using transformers, PIM models can be automatically transformed into PSM models which then can be used for further steps (e.g. IDL, C++ code or PDL generation). The tool chain supports also the Reverse Engineering process.

The following sections describes achievements for all work-packages of the project. Specifically:

- A definition of the **Operational Concepts** and their expected impacts, including a review of the State-of-Art technologies and systems, and a careful study of the major aspects related to the

"Next Generation 4D HMIs" has been conducted in the first part of the project. A brief description oh these activities and their results is reported in the section "Operational Concepts".

- The development of an appropriate **life-cycle** for the construction of the AD4 demonstrators - taking into consideration aspects like Component Based Software Development, use of CORBA and CCM middleware, use of MDA (Model Driven Architecture) approaches and tool chain – has been conduced in the framework of the project (particularly in the first part). A brief description oh these activities and their results is reported in the section "Life Cycle development".
- The construction and on-site integration of **demonstrators** in a simulated ATM control centre, tested by air traffic controllers, has been conducted in the second part of the project

- **Evaluation and assessment** activities to assess the AD4 operational concepts according to a well established methodology (i.e. MAEVA)

2.4.1 Operational Concepts

Operational Concepts work-package aimed at defining the operational basis of the project through a careful analysis of the operational work. The objective was to identify situations and scenarios that would benefit from the adoption of innovative three dimensional displays and virtual reality technique in the air traffic control domain. Furthermore a review of the State-of-Art technologies and systems, as well as a careful study of the major aspects related to the "Next Generation 4D HMIs", was conducted in the first part of the project as part of the activities of this work-package.
Specifically in the "Operational Concepts" work-package the following activities were conducted:

- The Operational concepts for the approach sector were investigated by means of several and effective interviews and visits to the Rome Ciampino Control Centre with a strong and fruitful collaboration of controllers and ENAV.
- Activities for the investigation of the Tower sector are then undertaken in the Tower of the Rome Fiumicino Airport, resulting in the additional issue of the Operational concepts report.
- The relevant key factors resulted by the above investigations and the findings related to the overall assessment of the potential impact in the ATC sector, lead the Consortium to focus the activities on researching the Approach and Tower sectors.
- The State of Art for systems and technologies was investigated and resulted as the preliminary assessment of the potential technologies to be used in the project developments.
- Current standards for ATM context were studied, to support subsequent activities in the project. Further assessment of standards should be helpful for the
- Major aspects related to the next generation 4D human machine interfaces in the ATM context, including the identification of concepts of interactions related metaphors/human factors and psychological aspects were studied in relation to the results of the Operational Concepts investigation of the Approach Sector and Tower sector.

Operational Work Analysis

Operational Work analysis for both Approach and Control Tower environments were conducted to elicitate operational needs and requirements related to the adoption of thee dimensional displays in the air traffic control.

The methodology and the Human Factors principle of Ecological Interface Design approach provided the theoretical foundation which lies behind both the operational work analysis studies in the Approach and Tower control.

We referred to the Contextual Inquiry as a basic methodology to conduct the Operational Work Analysis. This is a well known research technique in the field of user interface design that implies a close understanding of the final users of a system, in order to understand what they are trying to achieve, their goals and strategies. This approach consists in a field study of a few selected individuals in order to reach a broader comprehension of the work practices across all the customers.
During the operational work analysis we articulated the Contextual Inquiry in the following four phases (see also Figure below):

- Data collection: a field study of a sample of the user population operating in a real working context (Rome Terminal Area Facility) was carried out;
- Data analysis: the data gathered were reviewed and transcribed in a ordered and structured manner in order to have a repository of the observed episodes and the associated controller's problems. This part of the analysis iterate once with the phase one;
- Scenario definition: based on the review of recorded episodes, common problematic aspects affecting the controllers decision processes were clustered in eleven scenarios;
- Requirement elicitation: the understanding of each scenario lead to the extraction of the associated visual requirements according to a well known human factor principle, the ecology of the human machine interface.

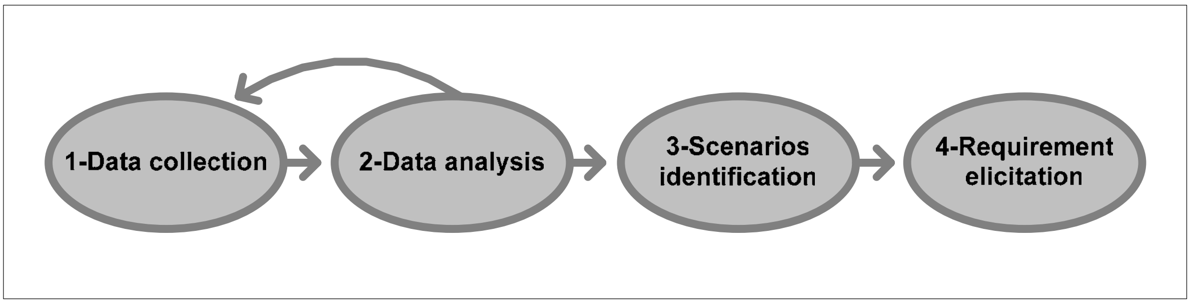


Figure 11: The phases followed to identify the user visual requirements. Between phase 1 and 2 there is an iteration since they were carried out twice.

Operational Work Analysis for Approach Control was based on a field study of the Ciampino ATC Centre in Rome. We conducted 15 ethnographic interviews, 6 ethnographic observations and 3 CDM interviews. The workload levels and the modernity of the control centre made it useful as representative of the tasks and work likely to be encountered in Approach and Departure control. 11 typical yet demanding operational scenarios were identified from which we derived four Representation Design Requirements; and five Recommendations about the direction of the direction that the technology solution should take.
Four Representation Design Requirements were identified, based on the Human Factors principle of making visible the constraints of the airspace ecology, and on an analysis of 11 operational scenarios.

- Discriminating vertical separations: information concerning vertical separation is not provided by the current radar display. This has an implication in a series of situation where the controller has to mentally calculate the actual and near future position of the aircraft;

- Volume representations: the 2D air space monitored by the controllers is actually a 3D space, were 3D "obstacles" exist and must not intersect with aircraft trajectory. Controllers need now to keep in their mind these restricted spaces;

- Intercept and trajectories representation: controllers continuously make predictions about the evolution of the situations and need to ensure aircraft follow their imagined planned trajectory from a point to another in space. All these computation are provided through mentally projection since not support is provided by the interface.

- Support shared representations: many decisions about trajectories and sequence requires a close collaborations between controllers, but this aspect is not considered in the actual user interface.

Eleven operational scenarios supporting each Representation Design Requirement were also identified in the process. These scenarios, grouped according to the four Representation Design Requirements, are listed below:

(a) Discriminating vertical altitudes
- Projecting vertical separation of intersecting trajectories
- Transferring aircraft between sectors
- Managing holding stacks

(b) Volume representation
- Dealing with cumulonimbus, clouds and weather
- Military restricted airspaces
- Considering the airport's surrounding topography
- Combination of 3D airspaces

(c) Intercept and trajectory representation
- Intercepting the Final Approach fix
- Tracking and updating military aircraft behaviours

(d) Supporting shared representations
- Negotiating trajectories in front of the screen
- Knowing who is controlling each aircraft

In the Tower domain the data collection for the study was conducted over 8 days. We conducted 50 unstructured interviews with controller's who described their activities and goals, their use of current displays, and the identification of the most critical challenges facing them in their work in the tower. These challenges include the impossibility to see some aircraft maneuvering in the apron or parking areas due to obscuration by surrounding buildings. We also collected over 80 hours of ethnographic observation of controllers engaged in routine activities. This is important to ascertain the nature of their information handling and team working strategies which then support the design of the 4D HMI. In addition, we also conducted 10 Critical Incident interviews that focused on actual situations that highlighted a number of non-routine safety critical situations that could reveal the nature of the air traffic controller's expertise in dealing with non-routine situations. The analysis of these data has been completed.

Eleven scenarios were identified, and based on their analysis and the application of the human factors principle of making visible the constraints of the airspace ecology, three groups of design requirements were identified. The scenarios, grouped according to two main Design requirements, are listed below:

(a) Knowing air craft position and state

(i) Apron and Taxiway: Discriminating aircraft position and movement state

- Detecting aircraft state o apron and taxiway;
- Dealing with separations at Tango 6 parking stand;
- Dealing with Incorrect manoeuvring at Tango 6;
- Knowing promptly whether an aircraft cannot move during Push Back.
- De-conflicting aircraft on the taxiway;
- Identifying aircraft at the holding bay.

(ii) Runway incursion: Detecting aircraft movement state before a runway incursion occurs

- A simple runway incursion;
- A runway incursion during take off;
- A runway incursion during take off from Bravo Bravo;

(b) Maintaining an integrated picture of the situation for the tower controller

- Critical loss of separation between landing and take off;
- Verifying state of the runway during a land after procedure.

Next generation 4DHMI

A careful study of the major aspects related to the **next generation 4D HMIs**, driven by an extensive analysis of the Operational Work and Human Factors and an extensive assessment of safety and security aspects, has been performed in the first part of the project.

Analysis of the operational scenarios identified in the course of the Operational Work Analysis has led the Consortium to explore and define innovative 4DHMI concepts in Approach and Tower domains, such as the representation of time in space and 3D vertical separation visual cues. These concepts constitute the basis of the subsequent 4DHMI design activities being part of WP4 tasks. The use of Augmented Reality concepts has been also analyzed and proposed as a possible choice for the representation of the operational scenarios in the Tower domain to overcome current limitations (especially in visibility) by providing extra information in a synthetic form.

The field study done in the first part of the project has identified a set of relevant scenarios, capturing the most frequent or demanding situations faced by approach, ground and tower controllers; the in-depth analysis of the controller needs and problems for each scenario has highlighted several recommendations for visual interfaces to be used in the control tower domain, driving the AD4 project partners through the definition of those visual elements which can possibly improve air traffic controllers' spatio-temporal reasoning, decision making processes, and ultimately Situation Awareness.

While the identified visual elements represent the common basis for the design of an effective visual display for the approach phase and in the control tower, two different visualisation approaches have been taken into consideration and implemented. These are:

- a Virtual Reality (VR) approach, based on the visualisation of visual elements within a purely synthetic 3D virtual environment
- an Augmented Reality (AR) approach applied to the airport environment, where virtual elements are integrated into a view of the real world as seen by the tower controllers viewpoint.

Virtual Reality (VR) approach in AD4 is based on the visualisation of visual elements within a purely synthetic 3D virtual environment.
The use of VR in the ATM domain aims to increase controllers situation awareness:

- heterogeneous data such as earth elevation models (terrain), meteorological data (cumulonimbi), airspace information (restricted airspaces, holding areas, landing paths, …) are integrated and represented in a 3D manner, according to the principles of the Ecological Interface Design that consists in making constraints visible so that an operator can easily perceive the limits of the system;
- navigation capability are provided to navigate within the 3D airspace virtual representation and examine the controlled situation from different viewpoints.

The AR implementation of the visual interface aims at proving applicability of AR techniques in the control tower room and showing the benefits that such a kind of visualization can bring to the ATC domain. Some of these benefits include the capability for the controller to observe the real airport, as seen through the control tower windows, integrated by extra information displayed on top of it.

Airspace and airdrome 3D representation provides controllers with visual cues from which to extract information more easily. Such information can be used during their decisional process in order to:

- reduce cognitive load for air traffic controllers
- allow to develop interactive air traffic path planning and new forms of conflict visualization techniques for optimising safe traffic flow
- allow trainee controllers to develop more easily and quickly their own 3D mental model
- feel immersed within the controlled airspace
    - experimenting First Person View-Point
    - permitting 3D-Navigation into the scenario
    - providing different view-points (holding stacks, pilot perspective, localizer, …)
- improve objects manipulation by implementing interaction metaphors typical of VR environments

Concerning the tower environment, the advantages of using VR/AR are multiple; as the controllers need visual contact through the window, it makes sense that VR/AR can help when visibility becomes very low (fog, night, ...). Even if the controllers have visibility, too many objects may be difficult to track, therefore, VR technology should be able to improve the level of awareness of the tower controller.
Visibility and level of awareness are therefore the two main characteristics that VR/AR is supposed to improve.

One obvious way that can be used to improve both Visibility and Awareness is to use augmented reality. For this, head mounted devices with a transparent screen are usually used and additional visual data are overlaid to the real view.

For instance, a controller is able to "see through the fog" as he wears his AR mounted device. This can be viewed as a complementary device that is used only during critical situations. AR in the tower has the advantage of being a kind of evolution of the existing state (natural view), without changing their habit, AR is able to provide "advanced vision" for use during exceptional situations.

Model Driven Aspect

One of the main outputs of this work-package is the Deliverable D17 "Model Driven Aspects". This Deliverable is targeted towards the emerging Model Drivel Development paradigm. The Deliverable covers main concepts and specifics of a model-driven software development process. It also gives an overview on platforms and services in the ATM domain that are relevant for AD4 project. Among them is also the D3 platform called AD4 platform. Another important part of this deliverable defines the AD4 tool chain, which is used to develop the AD4 platform in model-driven way. Finally the deliverable introduces the handling of the non-functional aspect Security in the ATM domain and in particular in the model-driven AD4 tool chain. The main result of this task is the definition of the AD4 tool chain as a Model Driven Development Tool with a high degree of detail. So it was agreed that a subset of UML2 (called eUML = essential UML) is best for modeling the components of the AD4 system in a platform independent way. Furthermore a graphical detailed design at platform specific level can be made with the help of a specific CCM Modeling tool. This tool implements the UML Profile for CORBA and CORBA Components.

2.4.2 Life-Cycle Development

The AD4 development Life-Cycle was precisely defined in the course of the activities of work-package 3 "**Life-Cycle Development**". Specification of system requirements, definition of system architecture, life-cycle development concepts and the how-to-follow for engineering process activities, identification of the key concepts for MDA driven processes were delineated as part of the activities of this work-package.

System requirements

The consortium completed the Systems Requirements Report as the specification of the most relevant features of an innovative 3D displays for air traffic control. The framework and structure for specifying the systems requirements for AD4 was set forth as a prerequisite for the completion of this activity. The Systems Requirements Report is organized so to cover all the functional and non-functional requirements, taking into account operation al environments, reuse of platforms and inter-operability with ESCAPE and ATRES infrastructures. Besides, we translated the observations about operations as described in the Operations Concept Documents in the 4D HMI functional requirements statements. The requirements are also in a standard format (i.e. VOLERE) supported by a simple database that permits easy interrogation of the data set.

System Architecture

System Architecture was described at two levels: conceptual and physical. The conceptual (logical) architecture describes the system in terms of its major design elements and the relationships among them. This description uses an informal approach so to allow also non technical stakeholders to understand the parts (and their inter-relationships) that constitutes the AD4 system. In this sort of architecture a strong emphasis is given to the description of data exchanged among modules.
The physical architecture describes the system in terms of physical components. For physical component we mean a software artifact that exists also at source code level. Aiming to trace physical components from modeling to implementation and being the AD4 development lifecycle supported by

MDA (Model Driven Architecture), physical components are described in terms of both platform independent models and platform specific models (targeted to CCM) using UML as modeling language. Aiming the AD4 system to be component based, a strong emphasis is given to the adoption of a Component-Based Architecture.

Life-Cycle development

The Life-Cycle development process, starting from the analysis of standard lifecycle processes and techniques, has defined the AD4 lifecycle aimed at helping coordinating resources to achieve predictable results. A good lifecycle process provides guidelines and techniques to structure the work, increases the odds of being successful, and therefore provides value to the organization, the project and the project team. The value of using a lifecycle process appropriate for the project consists in ensuring that all of the necessary work is included in the initial estimates and the initial work-plan, helping ensure that planning is done before execution in all steps of the lifecycle and providing a basis for learning from and taking advantage of pre-existing processes, techniques and templates.

In order to manage the risk of imprecise and/or incomplete requirements as well as the implementation of inappropriate 3D/4D representation forms, a **lightweight iterative development process** has been adopted. Iterative development prescribes the construction of initially small but ever larger portions of a software project to help all those involved to uncover important issues early before problems or faulty assumptions can lead to disaster.

The adoption of such a development process type allows AD4 developers to focus on a small number of requirements a time giving them the possibility of producing the final system incrementally. New features are so added to an executable prototype made available in the early stages of the project Features implemented at previous iterations can be revised on the basis of user feedback.

As already mentioned, the AD4 project aims to define a life cycle

- being component based
- supporting model-based development

The AD4 tool chain, implemented in the course of the project as part of the life cycle development activities, allows us to combine these two aspects providing a proper modelling infrastructure based on the MDA (model-based development) paradigm and targeting CCM components (component based development) as the basis of our development effort.

In fact in the AD4 project physical components have been developed (from design to implementation) by using the AD4 tool chain, which provides an integrated development infrastructure for AD4 physical components.

The AD4 tool chain supports the MDA approach. This means that the AD4 system infrastructure can be modelled independently of the implementation platform, there is no need to model, e.g., platform-specific data types, or to make decision immediately which platform to take. By using transformers AD4 PIM models can be automatically transformed into the AD4 PSM for further steps (e.g. code generation).

A methodology to be used in AD4 to drive each "internal" development iteration was defined as well (according to the definition of the AD4 life-cycle, each official release is composed of a certain number of "internal" iterations).

Such methodology defines and makes use of a Requirement Matrix that lists all the requirements (as specified in the System Requirements report) assigning them a priority, a status, a feasibility judgment and allowing their traceability through the identification of dependencies and involved architectural components.

The AD4 Tool Chain

One of the key tasks of the AD4 life-cycle development was the implementation of the AD4 tool chain. The AD4 tool chain enables us to correctly implement the model-driven software development paradigm; its architecture is shown below:

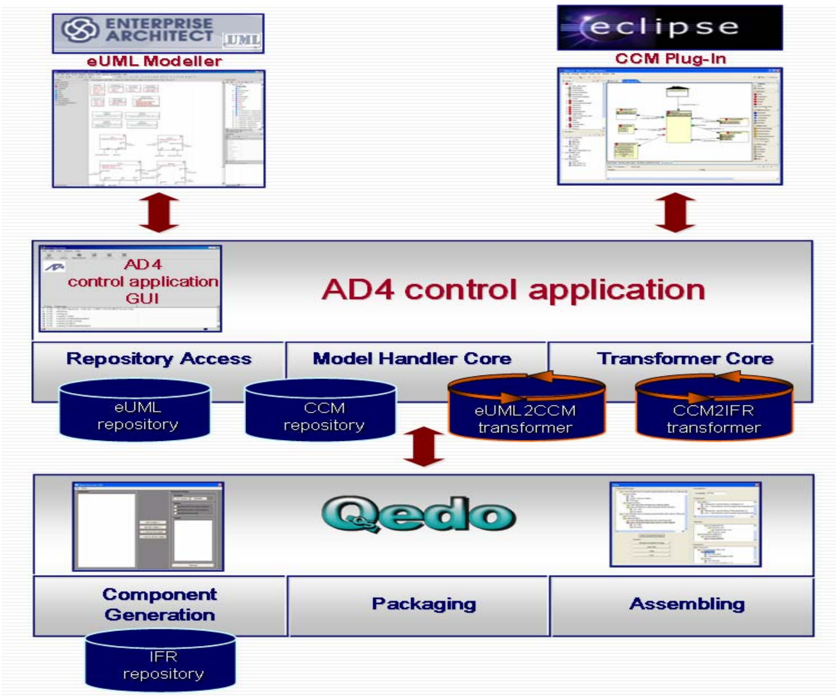


Figure 12: Overview of the AD4 Tool Chain Architecture

As outlined in the D17 deliverable ("Model Driven Concept"), it was decided to implement a Plug-in for the Enterprise Architect to allow PIM modeling based on eUML meta model.

It was also decided to us a custom made graphical tool, based on Eclipse, for PSM modeling of CORBA and CORBA Components. Furthermore, the Medini tools were used to generate model repositories and transformers. Additionally, a custom-made control application was designed to seamlessly integrate all different parts of the AD4 tool chain.

The Plug-in for the Enterprise Architect, that allows the PIM modeling and called eUML Modeller, has been used to create PIM models of the AD4 platform components. All relevant features of UML2 can be used. The custom-made tool (called Qedo Modeller) which is realized as graphical Eclipse Plug-in for refining models of AD4 platform at PSM (CCM) was used to visualize the AD4 models corresponding to PIM level models and add additional details to PSM model. This includes basic types and interfaces, components and homes, component implementation design and component deployment design. Model repositories for storing PIM and PSM models where generated out of the meta models defined in the first part of the project ("Model Driven Aspects" task). These repositories can be used to store models created by the Enterprise Architect based eUML Modeller or by the Eclipse based Qedo Modeller. First version of the AD4 control application is finalized. The AD4 control application can be used in particular to manage the PIM and PSM Models and to trigger transformations between such models.

The AD4 Tool Chain supported development activities by the automatic transformations of Platform Independent Models to Platform Specific Models targeted to the CCM platform and of Platform Specific Models (making use of UML2 profile for CCM) to Qedo enabled source code.
Among the others the AD4 Tool Chain is capable of

- Tool chain - Security integration through additional transformations aimed to produce PDL (Policy Definition Language) security policies
- IDL import to allow the use of pre-existing IDL interfaces and data structures in Platform Specific Models (this feature was used to import ESCAPE/ACE IDL interfaces into models of the AD4ACE gateways)
- Assembly modelling and transformation
- Assembly package creation (to replace the QXML tool being part of the Qedo Tool Suite)
- Refactoring of models (propagation of the change of an attribute name, propagation of the change of the signature of an operation)

Simulation and Demonstrator System Environment

Simulation and Demonstrator System Environment task was planned in order to investigate real environments and platforms for the later deployment of the AD4 system and to take into account logistic facilities as well as SW and HW constraints. A set of visits to ENAV experiment Centre, ENAV Training and Simulation facilities, the CRAV room of Ciampino, help defined an experimental platform for the AD4 infrastructure. Insights on demonstration and simulation environment were set-out by the responsible partners. Further activities in order to facilitate the real deployment of a demonstrator to meet the user needs are planned in the first two months of the second year.
Interoperation aspects were addressed in the "Simulation & Demonstrator System Environment" task by the interpretation of additional standard and proprietary formats for the persistence and exchange of airdrome related data
Specifically the following fromats have been supported

- GDB (Ground-DataBase) airdrome data format
- DAFIF ((Digital Aeronautical Flight Information File)) airdrome data format
- SCA (Surface Conflict Alert) exchange format

2.4.3 Core Components

The AD4 3D Radar Display is the result of a complex connection between COTS modules, ATC systems, gateways and very advanced visual applications. Most of these components were already available and used in operating environments (i.e. ATRES and ACE simulators), other components were developed reusing a large amount of existing software libraries (i.e. AD4 visual components based on D^3 architecture) or starting from scratch. Nevertheless, the AD4 system can be considered as the integration of well-consolidated components and new applications created in occasion of this project.

The AD4 core components have been implemented in work-package 4 "**Core Components**". Interoperation aspect and support of standard exchange formats, design and implementation of 4DHMIs, middleware and security aspects were addressed as part of the activities of this work-package.

Service Control Centre & Data Fusion

Service Control Centre & Data Fusion task was executed to handle component based operations for D^3 system and the usage of ASTERIX data, preliminary to the functional interoperability by means of the infrastructure. AD4 project has placed a strong emphasis on interoperability with ATC components and simulation platforms. In this context AD4 was integrated with well known simulation platforms like ESCAPE by Eurocontrol and ATRES by Vitrociset and adopted consolidated interfaces in the field, like the ones defined in AVENUE, as well as standard exchange formats like ASTERIX.
The **AVENUE** EC project (4th FP) has proposed a standardized architecture for ATM validation platforms. 'Standard' in this context means that it is a commonly agreed view among several key actors (ATM Supply Industry, ATSP and R&D establishments) within the ATM domain. AVENUE has defined a very interesting logical model for the ATM domain as well as **Data Dictionaries** and **Interfaces** (also evolved in the course of the **GATE-TO-GATE** Project) to promote interoperability among components developed by companies actively involved in the ATC field. Among the others, AVENUE architecture has been adopted for the ACE (AVENUE Compliant ESCAPE) simulation platform. Using AVENUE Data Dictionaries and Interfaces (an AVENUE-compliant AD4) we make possible to use AD4 with other AVENUE-compliant ATC components and adopt a well known and consolidated logical model. ASTERIX is a protocol for the exchange of data between different systems (e.g. ASTERIX cat. 062 for radar tracks).We have developed an "AD4 ASTERIX gateway". The "ASTERIX gateway" is responsible of converting operational data from the ASTERIX format to formats suitable for the AD4 system.

The extension of the NEXT D^3 (D-cube), a 3D open Virtual Reality component based platform, was set-out in order to incorporate the various ATM Tower and Approach scenario. D^3 technology uses CORBA as middleware. The modules of the AD4 system can be classified as belonging to two large categories as Data Providers (air traffic, surface traffic, weather and terrain data) and Data Consumers (the AD4 4D Controller Working Positions). All data provided by Data Providers will flow to the AD4 4D Controller Working Positions where they will be merged and presented to the users of the system. Not all the modules above will be developed from scratch in the course of the AD4 project. In particular the Air Traffic and Surface Traffic data providers will derive from the integration of AD4 with well consolidated simulation platforms such as ESCAPE by EUROCONTROL and ATRES by Vitrociset. In this case the AD4 project will develop just the components needed to access the services provided by such simulation platforms. For the above reason some AD4 components will derive from reuse of the corresponding ones available within the D^3 system. These components will be properly enhanced and adapted so to use CCM/Qedo middleware instead of plain CORBA. The AD4 project aims to focus on both the APPROACH and TOWER sector. Since in general some differences exist in the two domains, for simplicity of description the following two sections will provide different, even though similar, logical models of the AD4 system in these two domains[2]

Middleware

One of the key objectives of the Middleware task was the extension and adaptation of the already existing Qedo/MICO middleware to make it fit to the special needs of AD4. It was planned initially to start this task after the first reporting period. However, during the first months it was agreed to start with activities in this task earlier, to provide as soon as possible an up-to-date and for AD4 needs tailored Middleware Platform.

Capabilities of CORBA ORBs (Orbacus and Mico) to support AD4 component based infrastructure and to asses interoperability matters (e.g. ESCAPE vs. Qedo CCM platforms) were assessed.

[2] See insights on the Preliminary Architectural Design document

Qedo has been improved during the two years of the project: several bugs have been fixed in new versions (Version 0.8.3 from June 2006 and Version 0.9.0 from November 2006).

The main achievement in this task has been the finalisation of the Qedo Modeller, which is an Eclipse implementation of the OMG's UML Profile for CORBA and CORBA Components Standard. The Qedo Modeller has been extended to deployment concepts for an automatic generation of deployment description out of models. Since the AD4 tool chain is tightly coupled with Qedo platform, during the second period of the project the tool chain has been improved and extended, for example to the additional support of the security aspects.

Qedo/MICO was successfully used to develop and deploy CCM components acting as gateways towards the ACE platform. Interoperation issues towards the middleware used in ACE (OASIS, based on ORBIX) were successfully faced and solved.

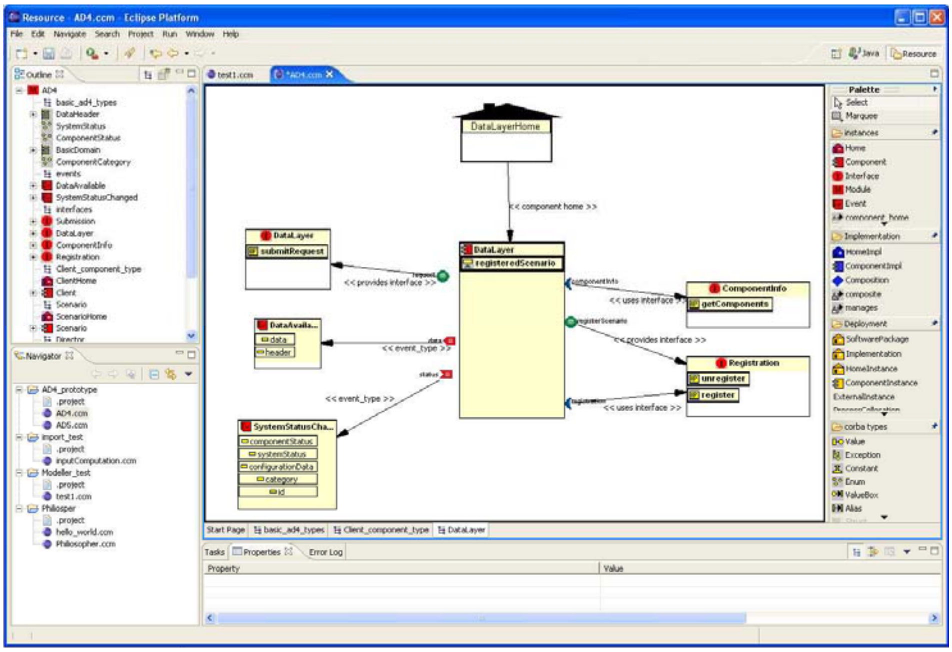


Figure 13: Qedo Modeller

<u>IT Security</u>

Security task studied and defined concepts for integration of Security Architecture into Qedo. Security concepts discussed in the fist reporting period and requirements for improving Qedo with integration of security aspects have been implemented in the new Middleware version of Qedo and OpenPMF called SecureMiddleware.

Main contribution to make SecureMiddleware more reliable was the improvement of MICO, the underlying ORB. MICO is well known as a stable ORB for standard client/server type applications. In Qedo based applications, with a much more distributed architecture and much more in- and outgoing connections between the ORBs, we identified instabilities and problems. To resolve these issues, we rewrote the connection handling and fixed a large number of bugs in the multi threading code, in the implementation of DSI/DII and other parts of the ORB. This greatly improved the overall stability of the ORB even under very demanding conditions, for example on very fast SMP systems, as extensive tests have shown. We also improved MICO's platform support, e.g. for Microsoft Windows, Solaris and HP-

UX, and integrated bug fixes and new features from the MICO community. We finished the clean integration of the Qedo CCM implementation, of MICO, the underlying CORBA ORB, and of OpenPMF, the policy management framework used for the definition, management and enforcement of security policies.
One of the important achievements in this task is the final implementation of the PDL generator, which is a part of the tool chain and automatically generates high assurance security policies from platform-in depended models.
Another very important result is the ObjectWall IIOP proxy. ObjectWall was used for the Secure Testing Environment (STE), an integration of the Escape simulation system running at SICTA (Naples) and the 4D display at Next (Rome). An interface and a configuration tool for runtime management of ObjectWall, including adding and removing of object references without restarting the proxy, were added in the second year of the project. STE was used for developing and debugging purposes, and to demonstrate a secure integration of ATC systems. The STE consisted of ObjectWall instances collocated with SICTA's and Next's firewalls. The STE allowed to securely send flight data from the Escape installation at SICTA over the Internet to the AD4 visualization system under development at Next. During the installation of the STE, which was done with our assistance, we fixed a bug in the MICO Interface Repository used by ObjectWall. In addition, we also had to add functionality for handling Network Address Translation to ObjectWall, as requested by SICTA, and to improve the handling of CCM events. A better policy management for the OpenPMF Policy Management Framework was implemented to be able to update security policies at runtime (complete runtime policy management system). A central notification of security events was also implemented as well as a GUI supporting policy editing and updates, PEP management and notification handling.

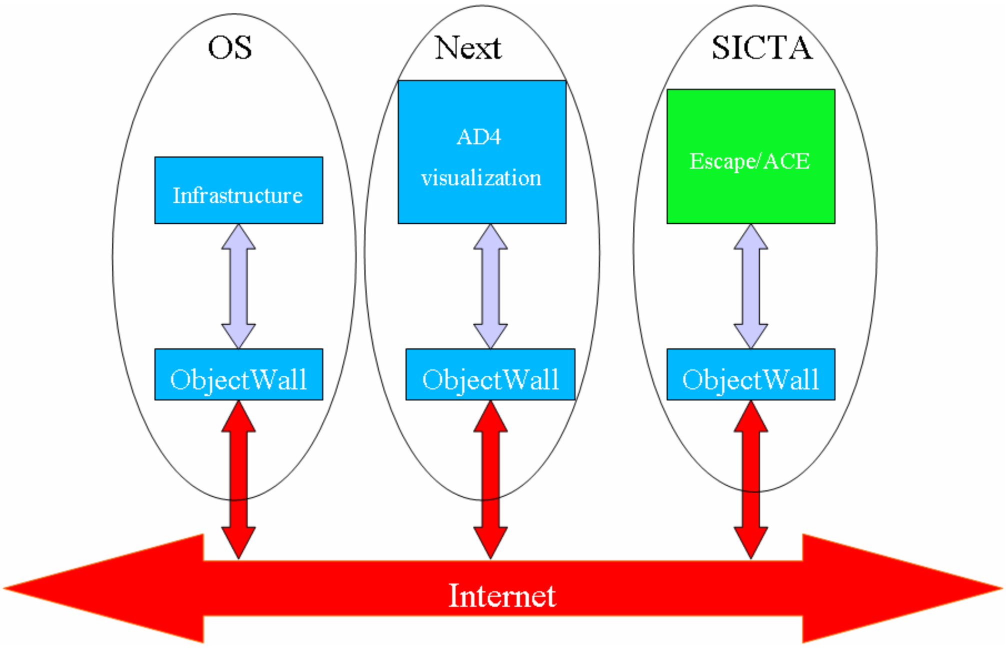


Figure 14: STE architecture

Applicative Components

Applicative Components task was early used to assess the capability of infrastructure to host ESCAPE CWPs and real operational simulation Components (such as ATRES and ESCAPE simulation platforms). This task was used to further explore components and data available in the real operational simulation platforms targeted by the AD4 project (ACE and ATRES). Interfaces towards these platforms (i.e. the AVENUE and ACE CORBA-IDL interfaces and data types) were carefully analysed as the basis for the design and implementation of the AD4ACE and AD4ATRES families of gateways.

Integration with simulation platforms

The integration with the ESCAPE/ACE and ATRES simulation platforms was completed as one of the main results of this work-package.

The ACE platform was successfully used to

- simulate air traffic to implement Approach Operational Scenarios relevant for the evaluation of the AD4 4DHMI concept in the Approach control.
- conduct air traffic simulations
- demonstrate the capability of the AD4 system to display approach scenarios

The AD4-ACE integrated system was successfully used during Real-time Human-in-the-loop simulations at SICTA premises with the involvement of operational air traffic controllers to evaluate the AD4 concept.

CCM components were successfully implemented to achieve the integration between AD4 and ACE. Such integration involved development activities on both the ACE side (development of components based on the OASIS middleware) and on the AD4 side (development of components based on QEDO). In detail the following set of gateways were developed to ensure the AD4-ACE interoperability :

- on the ACE side
  - a gateway (an ACE component) that subscribes to the ACE platform and forwards events to AD4
- on the AD4 side
  - a gateway for receiving radar tracks updates from ACE
  - a gateway for receiving flight plans data, both initial and updates, from ACE
  - a gateway for receiving correlation data from ACE
  - a gateway for receiving supervision events and simulation time from ACE
  - a gateway to get Area Proximity Warnings, Short Term Conflict Alerts and Minimum Safe Altitude warnings from ACE (safety net)

The Qedo controller was used to start-up, control the Qedo runtime environment and deploy AD4 Qedo components. All the AD4 Qedo components were packaged into a single CCM assembly package.

The ATRES platform was successfully used to

- simulate airdrome movements in order to implement Control Tower Operational Scenarios relevant for the evaluation of the AD4 4DHMI concept in the ground and tower control.
- conduct air, ground (airdrome) and combined (air + ground movements) simulations.
- demonstrate the cabability of the AD4 system to display approach + tower integrated scenarios
- demonstrate the capabilities of the AD4 system to act as a 3D Radar Display and interoperate with external data feeders able to provide data in standard formats (i.e. ASTERIX cat.062)
- implement a "mobile" demonstration system to be used at exhibitions and dissemination events. In fact the AD4-ATRES integrated system was successfully used at AeroDays 2006, INO Workshop 2006 and ATC Maastricht

The AD4-ATRES integrated system was successfully used during Real-time Human-in-the-loop simulations at SICTA premises with the involvement of operational tower and ground controllers to evaluate the AD4 concept.

AD4 components were successfully implemented to achieve the integration between AD4 and ATRES. Such integration involved development activities on both the ATRES side and on the AD4 side. In detail the following set of gateways were developed to ensure the AD4-ATRES interoperability :

- a gateway for receiving radar tracks updates from ATRES
- a gateway for receiving flight plans data, both initial and updates, from ATRES
- a gateway to get Surface Conflicts Alerts from ATRES (SCA)

4DHMI design and development for Approach and Tower sectors

Human Machine Interfaces development process in AD4 consisted of a specification process, where the HMI is being defined and specified, and an implementation process, where an HMI implementation is being produced. The specification process was mostly based on the methodology currently adopted and implemented in MMISE. MMISE is an HMI specification collaborative engineering tool tested in collaboration with NASA and ESA. In the course of the project MMISE has been tailored to the needs of AD4. According to this methodology HMI design is conducted at both conceptual and physical levels. Mock-ups and executable prototypes are used as much as possible to get early usability feedback from final users. Such a feedback is used to revisit decisions taken during in the HMI specifications activities.

4DHMIs for Approach and Tower sectors were finalized (designed and implemented) to represent operational situations (scenarios) identified in the first part of the project in the Operational Work analysis. Results of these activities are a series of air traffic displays capable of both 3D visualization and interaction. Specifically the following areas of investigation and technological development were addressed as part of the activities of task 4.8 (4DHMI Control-Centre), task 4.9 (4DHMI - Tower) and task 4.10 (4D Components):

- 3D Radar Display
- Augmented Reality in the airport environment
- Future Flight Concepts

The **AD4 3D Radar Display** was finalized. It constitutes the main technological development result of the project. The AD4 3D Radar Display provides controllers with airspace, air traffic, terrain and meteorological information elements within a purely synthetic 3D virtual environment.

The AD4 3D Radar Display is based on D3 technology.

D3 framework was enhanced and tailored to the requirements of the target system. Specifically the following features were added

- Semitransparent System Control Panel to perform system control commands
- Semitransparent Popup windows to display the list of active flights and flight info for each selected flight
- Adaptive 3D mouse sensitiveness
- Automatic (Smooth) Camera Transitions
- Quick access to a top view (north on top of the screen) to allow user to easily access the global picture
- Rapid access to fixed views (virtual preset 3D cameras) to allow controllers to navigate through all "sector traffics"
- Adaptive history dots size to resize history dots on the basis of the distance from view-point

- 2D planar (coordinated) view to improve spatial awareness and orientation in the 3D scene. Using the 2D planar view it is possible to change position and orientation of the 3D camera with an appropriate 2D mouse gesture (click and drag) done in the 2D planar view (map-based navigation)
- Standard mouse gestures to navigate within the 3D environment without the use of specific six degrees of freedom input devices (i.e. 3D mice)
- Representation of hypothetical trajectories (what-if)

Airspace (fixes, airways, holding stacks, restricted volumes, sector boundaries, ILS) and airdrome (apron, runway, taxiways, stop-bars, buildings) elements were represented to provide an ecological representation of the controlled sector.
Furthermore the following APPROACH operational scenarios were addressed and successfully represented

- Projecting vertical separation of intersecting trajectories
- Managing holding stack
- Dealing with cumulus and turbulences
- Military restricted airspaces
- Considering the airport's surrounding topography
- Combination of 3D volumes
- Intercepting the Final Approach Fix

Concerning the Control Tower domain, the following TOWER operational scenarios were addressed and successfully represented

- Identifying aircraft at the holding bay
- Critical loss of separation between a departing and arriving aircraft
- Verifying the state of the runway during a Land After procedure
- A simple runway incursion
- A runway incursion during take off
- A runway incursion due to misunderstood take off clearance

Algorithms were developed - as part of activities of task 4.10 (4D Components) -

- to compute vertical separation of intersecting trajectories (including hypothetical trajectories)
- to check if an aircraft is inside an holding stack and to compute the foreseen time-to-exit (the time to reach the exit point) from the holding stack
- to compute the intersection (position and foreseen time) between an aircraft foreseen trajectory (including hypothetical trajectories) and a military restricted volume.
- to find the intersection between the foreseen trajectory (including hypothetical trajectories) of an aircraft and a cumulus.

Algorithms to dynamically generate 3D VRML models of clouds (a "cumulus generator") have been implemented as part of the activities of task 4.10 (4D Components). Starting from a basic 3D model the generator can create a new model on the basis of input parameters like cumulus scale factor, colour, alpha value, noise parameter to modify the cumulus shape, etc.
An algorithm to interpreter METAR data and provide 3D clouds coverage in the airport surroundings was developed as well.

An **Augmented Reality demonstrator in the airport environment** was realized as part of the activities of task 4.9 (4DHMI - Tower). The intent of this demonstrator was to prove applicability of the

AR visualization technology in the development of an HMI for tower controllers, while taking into account some of the main 3D/4D visual concepts that derive from the needs of the Operational Scenarios identified in the AD4 project.
The basic idea was to augment video data of the airdrome (captured from a video-camera) with synthetic 3D objects conveying information on aircraft/vehicles moving in the airdrome (label, aircraft shape in wire-frame mode).
Specifically the following activities have been conducted

- development of specific AR-based 4DHMIs for the virtual airdrome representation
- development and use of a distributed IT infrastructure for the reception of position data provided by GPS/EGNOS equipment placed on board of airfield vehicles
- development of real-time video acquisition module
- development of a 3D graphic engine for visualization of virtual airport elements
- development of an augmented reality engine for combining video and virtual scenes
- development of components to convert GPS data telemetry into 3D graphical moving objects

Future Flight Concepts demonstrators (proves of concepts) were realized as part of the activities of task 4.8 (4DHMI - Control Centre). The intent of this demonstrators (3D Bubble, Distortion Lens, PIP) was to investigate on possible combined 2D/3D displays for air traffic control. Combined 2D/3D displays are those that present the viewer both a 2D and a 3D image of the same objects in the same field of view of the airspace.
Specifically the following activities were conducted

- development of specific 4DHMIs for the combined 2D/3D display virtual representation
- development of different 3D-in-2D air traffic visualization modules (3D Bubble, Distortion Lens, PIP), including GUI interface
- development of simplified air traffic data generator to feed data to the air traffic visualization modules

<u>DEM/Meteo and Airport data</u>

The main objective of the "DEM/Meteo and Airport data" task (task 4.11) was to select an Italian airport and to acquire all the relevant data for this airport related to the terminal area and ground data, geography and meteorological conditions.
To achieve this goal procurement, representation and modelling activities were conducted. Specifically

- Satellite Maps for rendering purposes (e.g. using the free services offered by NASA under the OneEarth project) were integrated within D^3 architecture.
- Milano Malpensa and Naples airdrome data (in AutoCAD format) were procured and translated to the GDB XML format
- Data surveys were conducted at Naples airport to collect airdrome data with video and GNSS data recording of a moving vehicle
- VRML models of Milano Malpensa and Naples airports were produced by the fusion of dynamically generated models with additional detailed models of specific airdrome areas (parking areas, buildings, …)
- textures of terrain were supported to provide on-demand photo-realistic representation of terrain in the airport surroundings.
- METAR data of the Naples airport were procured

2.4.4 Appointment of Demonstrators

Several demonstrators were implemented to demonstrate results achieved by the AD4 project to controllers, technical specialists and interested audiences at dissemination events
Specifically the following demonstrators were prepared:

- 3D Radar Display for demonstrating and evaluating 4DHMI in both APPROACH and AIRPORT ENVIRONMENT control,
- Augmented Reality in the AIRPORT ENVIRONMENT
- Combined 2D-3D displays
- Security aspects demonstrators
- MDA Tool Chain demonstrators

3D Radar Display

The AD4 3D Radar Display provides an innovative Virtual Air-Space representation for ATM systems, where 3D representations of air traffic/airport space and virtual/augmented reality techniques are accessible to the controllers.

Virtual Reality (VR) approach in AD4 is based on the representation of visual elements within a purely synthetic 3D Virtual Environment that provides a 3D perspective display of the ATC controlled sector. The implementation of such 3D Virtual Environment is based on a 3D framework, called D^3 (D-cube) developed by NEXT in a national research project. Such framework has been successfully enhanced and tailored to the ATC domain in the course of the AD4 project.
D^3 is a 3D Virtual Reality system for real time visual representation and manipulation of heterogeneous geo-referenced data such as DEM (terrain), meteorological data (clouds, pressure and wind fields), telemetry data, GNSS (satellite) and surveillance data (radar tracks).
D^3 framework is capable of both 3D Visualisation and 3D Navigation.
3D visualization results from the integration of heterogeneous data, structured into layers. Throughput and elaboration limitations are overcome by a scalable and distributed architecture.
3D Navigation is allowed by the use of both specific (3D Mouse, a 6 degrees of freedom device) and standard (classical mouse) input devices.

The AD4 system provides a 3D air situation display (3D radar picture). It allows to display all the phases of a flight allowing to follow aircraft from gate to gate.

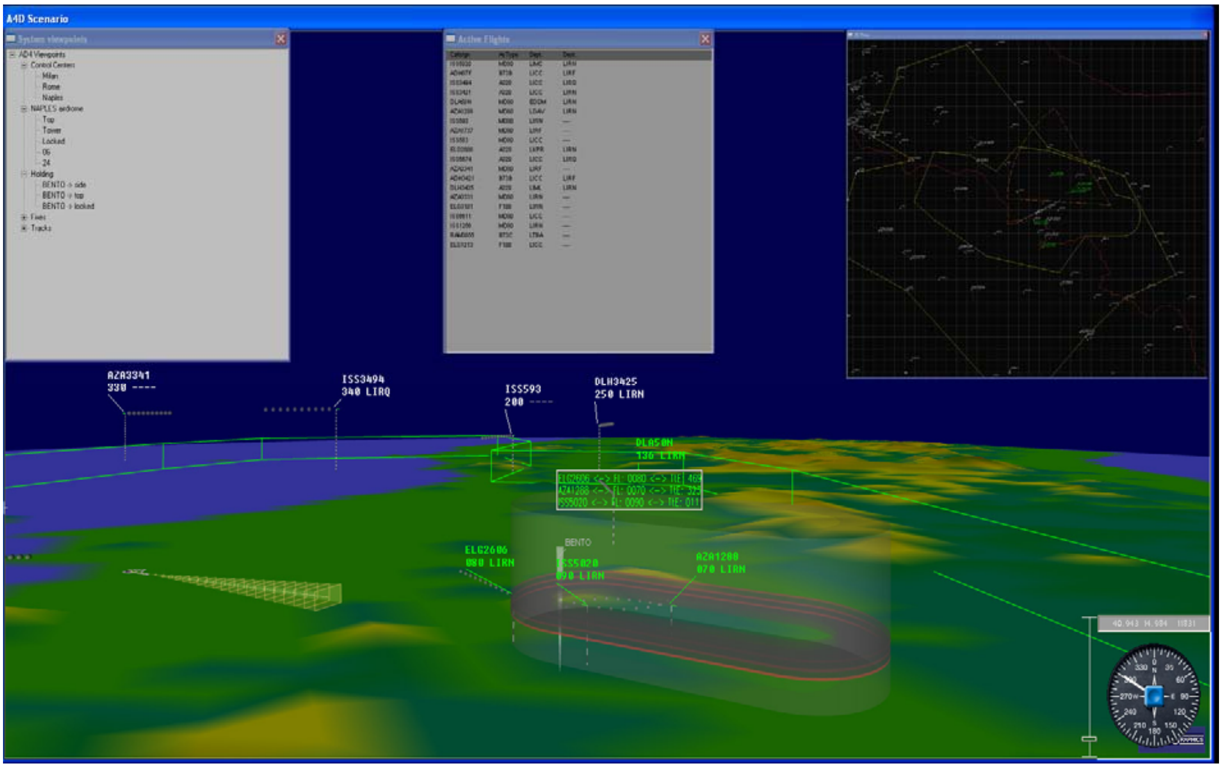


Figure 15: AD4 System display overview

The picture above gives an overview of the AD4 system display, illustrating the 3D airspace representation adopted in AD4 together with additional windows used to control the system.

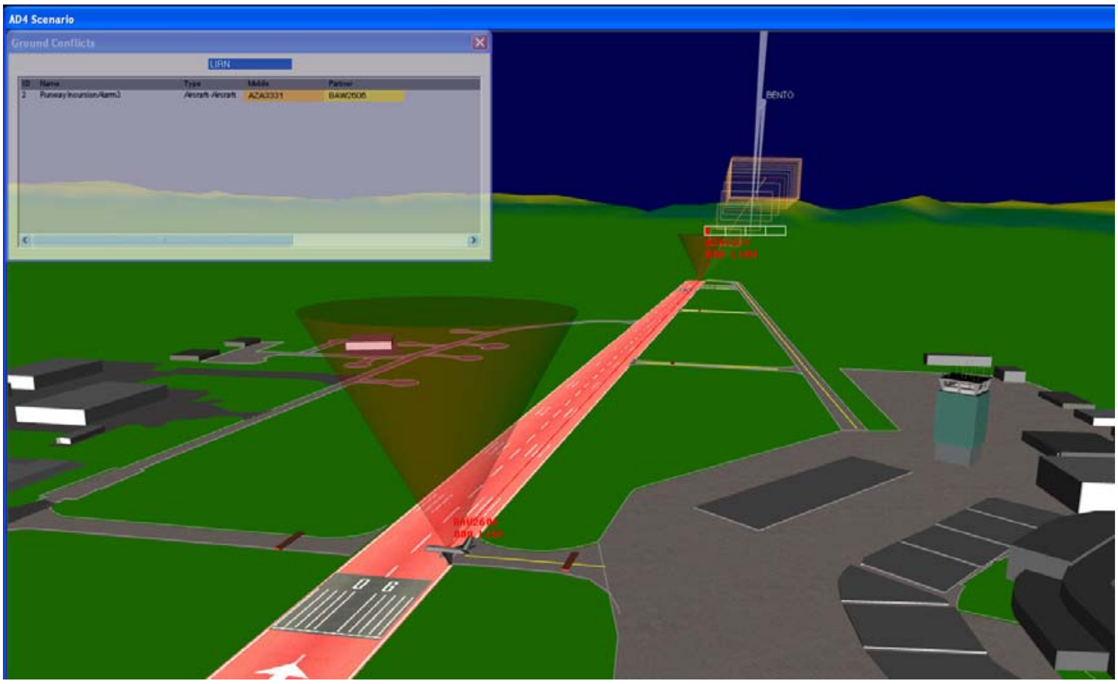


Figure 16. Runway Incursion visualization

The AD4 3D Radar Display is characterized by the following aspects:

- It is based on D^3 Virtual Reality framework
- It is Integrated and Interoperable with simulation platforms and ATC components
- Supports standard exchange formats (e.g. ASTERIX) and CORBA IDL interfaces for the ATC domain (e.g. AVENUE)
- It is characterized by an high degree of heterogeneity concerning
    - Hardware (Intel based systems, SUN and HP-alpha systems)
    - Operating Systems (Windows, Linux, SUN-Solaris, HPX,...)
    - Platforms (Component Middleware versus plain CORBA; Different ORBs like MICO, Orbix, Orbacus; Simulation Platforms; D^3 components)
- It is distributed and based on remote heterogeneous components interconnected via well-defined interfaces and providing data to be processed and/or displayed
    - D^3 components, like data feeders (terrain, weather, airspace, air traffic), and visualization components (3D Virtual Scenario)
    - components to interoperate with external systems like simulation platforms

To cope with its high degree of heterogeneity it has been decided to base the AD4 system on Secure CORBA and CCM (CORBA Component Model) middleware developed and/or maintained in the course of the project.

The AD4 system is capable to interoperate with well known and consolidated simulation platforms in the ATC domain, like Eurocontrol ESCAPE and Vitrociset ATRES. Such integrated environment has been successfully used to evaluate the most relevant 4DHMI concepts and representations by Real-Time Human-in-the-loop Simulations with the involvement of controllers and simulation of the operational environment.

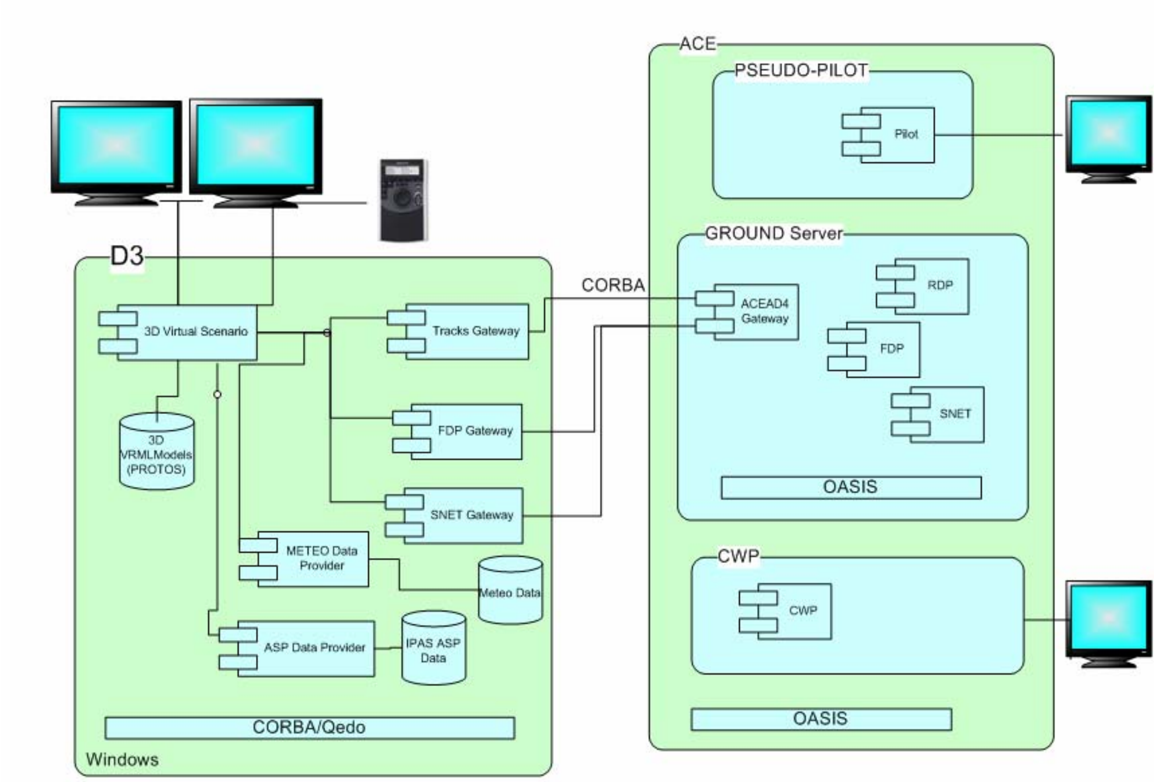


Figure 17. deployment view of the D^3-ACE integrated platform

Augmented Reality in the AIRPORT ENVIRONMENT

The purpose of the AR demonstrator is to prove applicability of the AR visualization technology in the development of an HMI for tower controllers, while taking into account some of the main 3D/4D visual concepts that derive from the needs of the Operational Scenarios identified in the AD4 project. Those 3D/4D concepts are partially revisited and utilized for the AR HMI, which thus appears to be strictly related to the D3-based Tower HMI.

The capabilities of the demonstrator are mainly focused on visualization, rather than interaction; indeed, AR provides a way to visually augment the real world perceived by the controller with synthetic 3D elements generated by the system. 3D synthetic (virtual) objects are rendered and displayed in a perspective view, which is overlapped to the real one, according to the real viewpoint and field of view of the user.

Augmentation consists not only in representing the 3D models of real objects (e.g. to replicate a wire-frame 3D aircraft or building on top of the real ones), but also in introducing new elements, such as aircraft labels or time-related 4D (3D space + time) visual elements (e.g. future position of aircraft, acceleration,…) that can provide additional information to the user about the real scene being observed.

Interaction is mainly concerned with the selection of those synthetic data layers to be displayed, i.e. the controller is allowed to enable/disable 3D/4D virtual objects, and the general visualization settings.

From the technological point of view two different approaches have been identified as possible candidates: a full AR approach and a simplified one.

- Full AR approach consists in the use of head tracking devices, to track user's view-point movements, coupled with semi-transparent display devices where to present synthetic images registered with real objects (present in the real world).
- Simplified AR approach consists in the use of video cameras placed at fixed positions in the airport and standard monitors to display synthetic images superimposed on images coming from video cameras. No tracking devices are used and 3D scene is reconstructed from fixed camera position, orientation and field of view.

The opportunity of achieving a rapid development of the AR experiment and non-intrusiveness of the approach (no need of controller's head tracking system and see-through displays) has led the Consortium to select and implement the simplified AR approach.

It must be mentioned that, despite the simplicity of such an approach, the AR system developed in the AD4 project could be easily adapted to specific operational needs of airdrome control. Presence of occlusions in some areas of the airdrome is a possible case of use. In this situation video-cameras are commonly used to frame the occluded airdrome area. In presence of visibility problems, due to night or bad weather conditions, the simplified AR approach can be a solution.

Furthermore it must be noticed that tiled displays, where images coming from different cameras are merged to provide a higher field-of-view, can be easily coupled with our simplified approach in the use of Augmented Reality techniques.

The AR system is made up of a set of software components running on a standard PC (desktop or laptop) and devoted to integration of heterogeneous data coming from different sources, such as video from camera, position tracks of aircraft and vehicles, airport geographic data, and to the actual augmented visualization at the Controller Working Position (CWP). This part of the system is also referred to as AR CWP.

The AR CWP receives surveillance data (positions and identifications) of moving aircraft and/or vehicles in the airdrome from mobile terminals that are installed onboard the relevant aircraft/vehicles in the airport area.
Surveillance configured EGNOS/GPS receivers, installed on board of moving vehicles, provide the position data. The necessary improved accuracy of GPS data and integrity of the Signal in Space are provided by the EGNOS augmentation system.
A communication infrastructure is responsible for managing the connection between the mobile terminals and the AR CWP. Such infrastructure is based on NEXT's XInfo™ infrastructure. XInfo provides all the necessary infrastructural functions, such as reliable communication between the terminals and the AD4 AR–based system, terminal secure authentication etc, to propagate the augmented satellite data within the system.

Video data are received from a camera (potentially even more than one) installed in the control tower, near the AR CWP, and looking at a selected part of the airdrome, thus having fixed position, orientation and field of view.
In the AR CWP, video data are merged with synthetic ones in order to generate and display the augmented scene. The augmented scene is actually displayed on a standard flat screen.

The figure below shows a very high level overview of the system architecture.

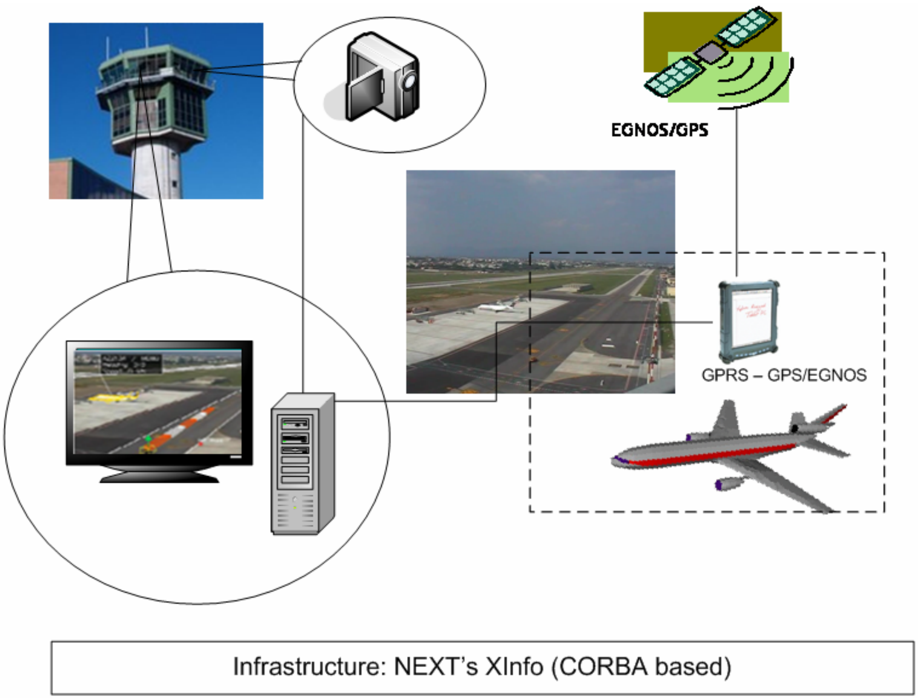


Figure 18: The AR demonstrator: system overview

The AR Display is composed of one monitor where the AR view, made up of the real airport view merged with the 3D representation of some of its elements, is presented in the AR main window.

Figure 19: Overview of the AR display

<u>Combined 2D-3D displays</u>

Future Flight Concepts category of demonstrators (3D Bubble, Distortion Lens, PIP) have been developed to investigate on possible combined 2D/3D displays for air traffic control.
Combination displays are those that present the viewer both a 2D and a 3D image of the same object in the same field of view. The displays are intended to support typical visual perception tasks in air traffic control. These tasks include the detection of separation between aircraft in the vertical plane, and the projection of the future positions of all the aircraft under control.
Future Flight Concepts refer to experiments on combined 2D/3D displays for ATC.

The **Bubble 3D** prototype has been created to experience some methods for being able to visualize three-dimensional information, without modify completely the classical radar visualization or, at least perform a smooth context switching between different visualizations.
The 3D visualization is represented as a projection, with a different perspective, of the 2D visualization.
The same information presented in a classical radar are displayed in the same way.
Aircraft are visualized as point with an information label, the trajectories laying on the plane as well all the other information.
A three dimensional bubble appear in the screen and permit to arise all the object that are inside it and provide additional 3D information.
The aircraft inside the bubble change their shape becoming a pyramidal wedges with the apex pointing in the direction of speed, the trajectory are visualized in three dimension.
The developed prototype has a lot of customization implemented in order to fit better and try to test several different configuration.
Different bubble models (disk, semisphere, sphere, cone (with infinite length)) are provided and for each model the user can change some parameters (height, size).
The type of 3D perspective is fully customizable: the user can change the view using the mouse and navigate with the help of keyboard. In this manner controllers can choose the best view to control better the flights.

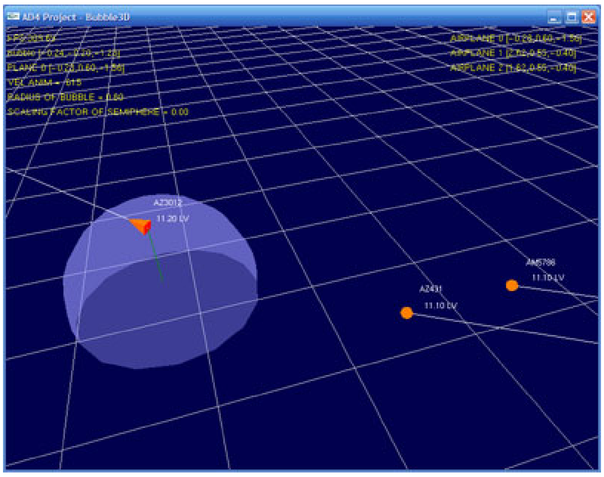


Figure 20: Bubble 3D display overview

The **Distortion Lens Display** is composed of one monitor where a 2D view "from above" of a portion of simulated airspace is presented to the user (controller), in the main Distortion Lens window. The window can either occupy the full screen area or a part of it.
The Distortion Lens main feature consists in the ability to display a localized 3D view, corresponding to a selected sub-region of the whole 2D view, within the overall 2D "radar-like" view of the airspace itself, the two views (2D and 3D) being merged together in a single visualization solution.
Such integrated display preserves continuity between those parts of the virtual scene that fall in the 2D view and those which fall into the 3D view (trajectories in particular).
The integrated visualization is obtained by implementing a transition zone at the interface between the two areas, where the 2D visualization is smoothly and progressively transformed into a 3D one, as shown in figure below.
The area to be displayed within the 3D view corresponds to a rectangular region and is interactively selected by the user. The current selected area is highlighted by rendering it in light grey color, while the 2D background is black (or dark grey).

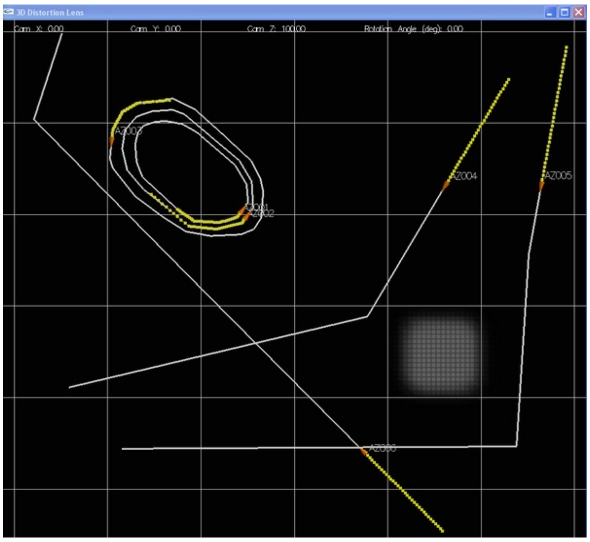


Figure 21: Distortion Lens display overview

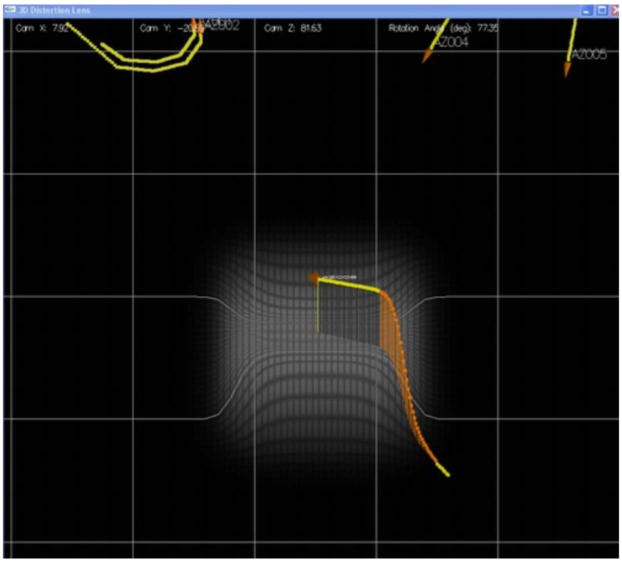


Figure 22: Distortion Lens: the 3D view is localized in the light grey area

The **Picture within a Picture (PIP) Display** is a presentation of a variety of different visualization/interaction styles for a domain specific application viz. the simulation of an air traffic control radar display. It presents (simulated) aircraft moving in the viewing window, and allows the user to visualize the aircraft in three main modes. Firstly a 2D only representation, secondly a 3D only representation and finally an integrated 2D/3D view using a specialised Picture-in-Picture (PIP) display on demand. The different visualization/interaction styles are available to evaluate the effectiveness of the different representations with regard to specific tasks in the ATC domain, primarily vertical separations. In addition to the major modes described here, additional HMI component are also deployed these include presentation of forward trajectory vector, drop lines to the ground, 3D temporal curtains, destination vector drawing and presentation of lines linking aircraft together.

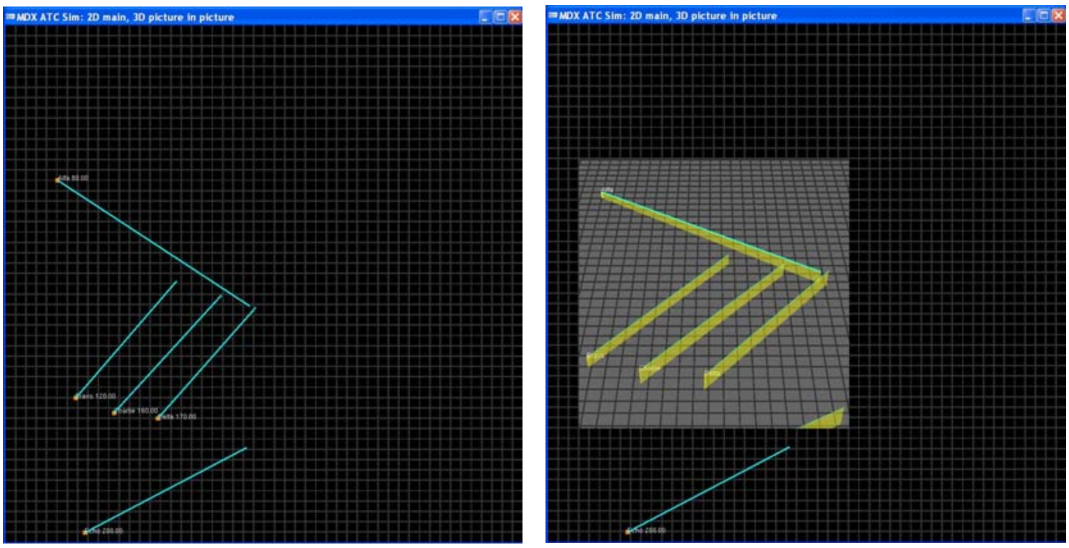


Figure 23, 24. Interacting with the "Picture in a Picture" HMI

When interacting with the "Picture in a Picture" HMI, user selects a relevant area in the 2D view, which then rotates downwards, thus turning in a localized 3D view (Fig. 52). The rotation is smooth to avoid the user to get lost. The localized view represents aircraft at their current flight levels. The "temporal curtain" represents their future positions and flight path profile.

The Picture within a Picture (PIP) Display was developed as an alternative innovative 3D-in-2D interface, in response to the display presentation needs for ATC controllers identified in the AD4 Operational Concept Report.

2.4.5 Experimental Activities

A series of experimental activities were conducted to assess and demonstrate the portfolio of results achieved by the AD4 project to controllers and technical specialists:

- **Evaluations**
- **Demonstrations**
- **Proves of concepts**

Evaluations have been performed to establish the "fitness-for-purpose" of the AD4 Operational Concept.
The AD4 Operational Concept consists in deploying 4D (Space plus Time) displays in order to enhance the presentation of the spatial-temporal information necessary for controller's job.
Following MAEVA methodology, high level evaluation objectives have been identified and mapped to a set of low level objectives with associated hypothesis, metrics and data collection methods.
In particular safety (mapped to both workload and situation awareness low level objectives), usability and acceptability have been identified as high level objectives of the AD4 evaluation activities.

Real-time simulation has been selected as the most appropriate evaluation technique and ATC simulation platforms, like ESCAPE/ACE and ATRES, have been chosen to feed the system with simulated operational data (i.e. radar tracks, flight plans) and events (i.e. conflicts).

Demonstrations have been conducted to demonstrate results/capabilities achieved in all the fields covered by the AD4 project (4DHMI in both APPROACH and AIRPORT ENVIRONMENT control, Augmented Reality in the AIRPORT ENVIRONMENT, Security, MDA and development life-cycle) to controllers and technical specialists as well as to a broader audience at dissemination events.

Proves of concepts have been conducted to assess ideas for future developments. Experiments on combined 2D/3D displays for ATC (3D Bubble, Distortion Lens, Picture in Picture) and Augmented Reality Evaluations/Demonstrations are the most relevant proves of concepts performed.

Execution of Demonstrators Test with Human in the Loop for the APPROACH 4DHMI
The evaluation took place at SICTA simulation room in Naples from 25th to 27th November 2006.
Four experienced air traffic controllers from the Naples Approach Sector were recruited to participate in the evaluation. Their experience included all of the ACT phases, and years of activity ranged between 10 years (1 subject) and 20 years (3 subjects).

The setting for the validation included:

- one measured sector, which is Naples Approach, including Naples Airport (LIRN) Airport and the military areas R62 and R63;
- three feed sectors, which are:

- TS/US sector, resulting by the combination of US and TS Rome Area Control Centres;
- Naples Tower
- Brindisi ACC.

For the simulation, three different scenarios were used. All scenarios lasted about 30 minutes and were conducted in a human in the loop simulation, i.e. controllers could assign instructions and clearance to traffic being in frequency with pseudo pilots, as well as controllers of other traffics.
The scenarios were collected during interviews with operational controllers in order to represent real traffic situations that might occur in Naples approach sector. The *Validation Plan* for Approach control available in the *D30_Evaluation and Assessment Report* document describes the rationale behind the validation scenarios and the link between these and the initial scenarios emerging from the early data collection in Rome, which are reported in the *D12_Operational Concept Report,* from which user requirements have extracted.

ID	**Scenario Theme**	**Critical Event**
1	Approach	Intruder aircraft breaks a landing sequence
2	Holding Stack	Emergency demand a quick descent of an aircraft engaged at the top level of busy holding stack
3	Final Approach Fix	Low visibility, one runway in use in one direction only. Coordination of landing and departures in opposite directions is required

Table 3. List of traffic scenarios used in the AD4 validation

Two adjacent working positions - planner and executive - were available in the simulation room. The subjects operate at the executive working position. The planner was operated by personnel from the Validation Team, as difference between this HMI and real HMI would have required extra training for controllers.

Both executive and planner used a 2D Barco LCD display placed in front of them as their primary display. This was operated by a mouse as in real setting. In addition to that the 3D/4D AD4 system was available on the executive working position. It consisted of two displays:

(x) a 3D radar display: this was the display that showed the information which was under evaluation. It usually displayed a 3D view of a portion of the sector.

(xi) a 2D navigation display: this monitor offered a top view of the sector upon which the controller could navigate and change the point of view of the 3D display.

The two AD4 displays were operated by an additional mouse which allowed firstly selecting an interesting portion of the airspace where to place the 3D camera. This was possible when the mouse was placed over the navigation display. Secondly the same input device allowed to navigate the camera back/forward, up/down when operated on the 3D display.

Controllers were also provided with a headset that enabled them to communicate with pseudo-pilots and adjacent sectors. There were no other sources of flight information such as paper flight strips available to the participants. Finally, an input device made of five buttons was placed in front of the controller. This allowed the collection of workload subjective measures.

The 2D radar display was placed in front of the controller as in a real life setting and 3D AD4 display under test was placed to the left of the executive working position, rotated at about 45 degrees to the controller line of sight. The navigation display was placed on the left of the 3D monitor rotated of about 90 degree from the controller line of sight. Overall this resulted in a Side by Side configuration, where users must search information across different display. Figures below show the display disposition.

Figure 25. The executive and planner working position used during the simulation. The display were as follow: planner 2D radar display (A), executive 2D radar display (B), executive 3D radar display (C), and finally executive navigation display (D), see text for description. In front of the controller(F) was also placed the input device for the Instantaneous Self Assessment Tool for workload measurement.

Figure 26: The experimental working position in operation, with the executive sitting on the left, and the planner on the right.

Execution of Demonstrators Test with Human in the Loop for the AIRPORT 4DHMI

The evaluation took place at SICTA simulation room in Naples from 24^{th} to 25^{th} Jannuary 2007.

Four experienced air traffic controllers from Naples Tower Control were recruited to participate in the evaluation. Their experience included all of the ACT phases, and years of activity ranged between 10 years (1 subject) and 20 years (3 subjects).

The setting for the validation included Naples Tower Control.

For the simulation, three different scenarios were used. All scenarios lasted about 30 minutes and were conducted in a human in the loop simulation, i.e. controllers could assign instructions and clearance to traffic being in frequency with pseudo pilots, as well as controllers of other traffics.

Scenario design was based on (i) general classes of critical events – ref. AD4*_D12_Operational Concept Report_Vol2: Tower Control* – and (ii) the contribution from ENAV air traffic controllers. This background made possible to reproduce unexpected traffic events that might occur in Naples Tower Control where the novel display could potentially ease the controllers' task. The *Validation_Plan* for Tower Control, available in the *D30_Evaluation and Assessment Report,* describes the tower scenarios presented during the simulation.

Table 4. List of traffic scenarios used in the AD4 tower validation

ID	Scenario Theme	Critical Event
1	Single Runway Incursion	An unauthorized aircraft enters the runway
2	Double runway Incursion	Two aircraft enters the runway at opposite ends, due to misunderstanding of take off clearance
3	Loss of separation between incoming and departing aircraft	An aircraft aligned and ready to take cannot move due to a broken undercarriage. While incoming traffic has been authorized to land.

Of the four Tower Control Working position – Planner, Ground, Coordinator, Tower – the simulation replicated the Tower Controller working position. A pseudo pilots was also available and he was sitting in a different room.

The 3D/4D AD4 system consisted of two displays:

(xii) a 3D radar display, which showed a 3D view of the airport

(xiii) a 2D display, which showed:

a. An Approach Window, offered a top view of the aerodrome that enabled the controller to monitor the approaching traffics, as in a real working position.
b. A Navigation Window: a small top view of the airport; this enabled the controller to understand where the camera point of view was located and where it was pointing at in relation to the airport, and to change it.

The two AD4 displays were operated by a 3D mouse which allowed firstly selecting an interesting portion of the airspace where to place the 3D camera. This was possible when the mouse was placed over the navigation display. Secondly the same input device allowed to navigate the camera back/forward, up/down when operated on the 3D display. Finally, Controllers were also provided with a headset that enabled them to communicate with the pseudo-pilot. There were no other sources of flight information such as paper flight strips available to the participants.

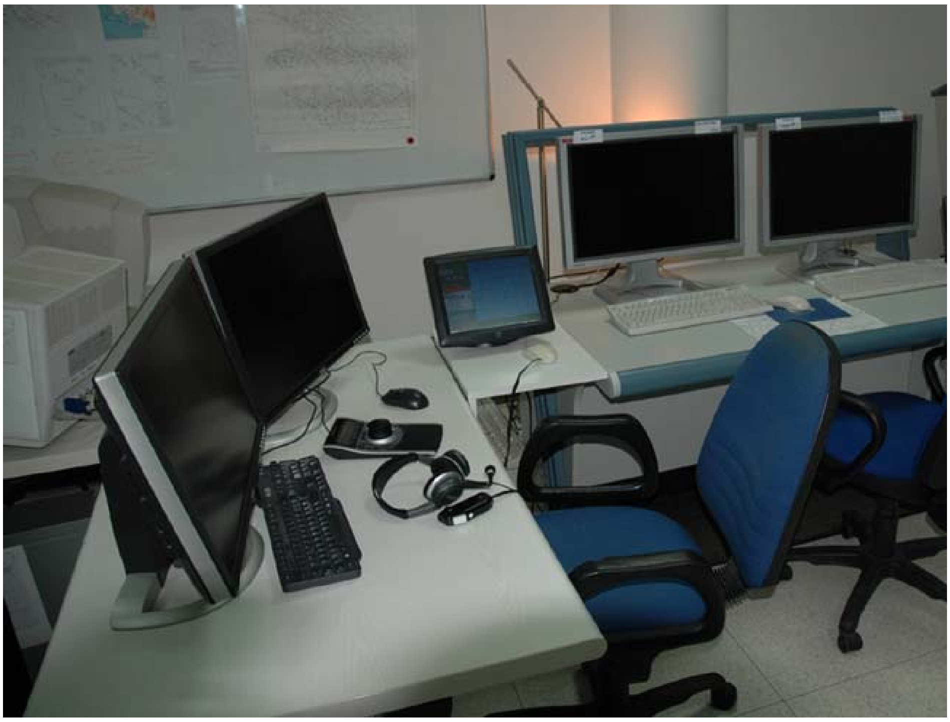


Figure 27. The simulated Tower Controller working position. The 3D display is locates in front of the operator. On its right, rotated of 20 degree, is placed the 2D display containing the approach and navigation window.

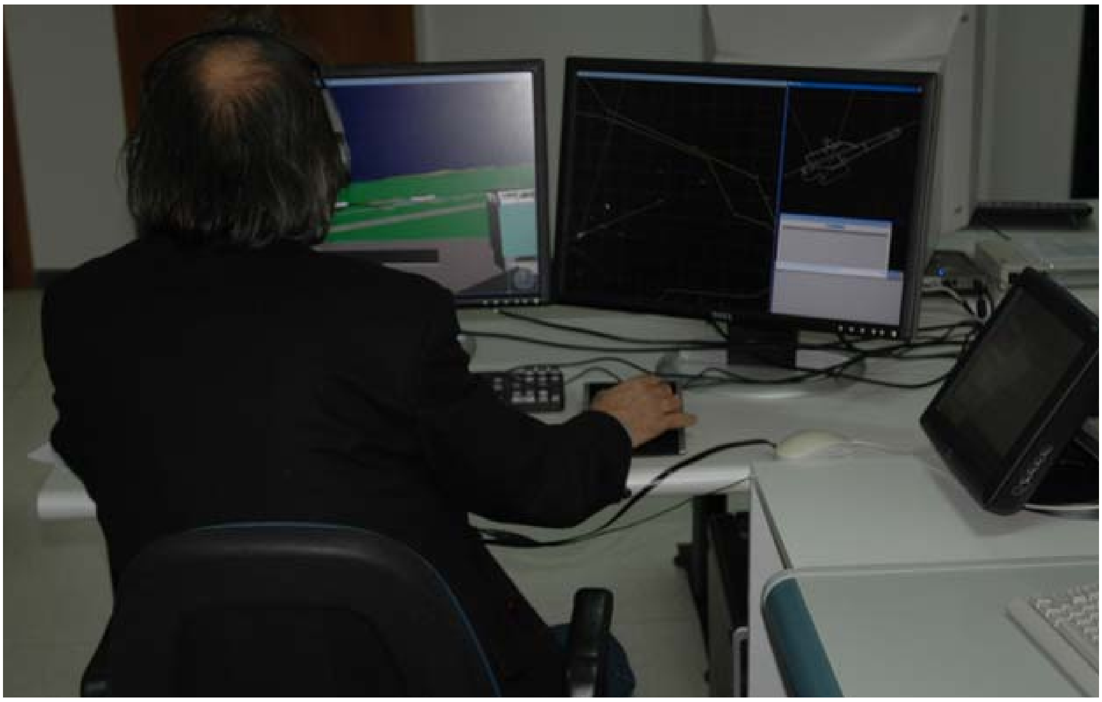


Figure 28. The Simulated working position in operation.

The 3D display was placed in front of the controller, and the navigation display was placed to the right of the controller, rotated at about 20 degrees to the controller line of sight. Overall this resulted in a Side by Side configuration, where users must search information across different display. Figures and show the display disposition.

Execution of Demonstrators Test for the Augmented Reality HMI in the AIRPORT environment

The activities took place at Naples Capodichino Airport the 22nd and 23rd of February 2007. In that occasion, the AR system was presented to two experienced air traffic controllers during a set of real traffic situations occurring in the airport.

The present study represents the second test of the AD4 tower HMI. The criteria to conduct the validation were set during the AD4 meeting carried out in London the 12th, 13th October 2006 at Middlesex University. In that occasion due to available resources (mainly a limited number of controllers) and existing constraints, it was decided to carry out a qualitative assessment of the AR HMI. Thus, it has not been refereed to hypotheses in any experimental sense, as the qualitative results would not allow any statistical hypotheses test.

Aim of this evaluation was to get a feedback from controllers about the use of AR visualization in the Tower Environment; the focus of the evaluation was:

- whether and why AR is valuable for tower controllers
- how AR affects situational awareness;
- what are the relevant usability issues implied in operating the AR HMI
- what is the acceptability of the AR system from operative personal, i.e. to what extent real tower traffic controllers would accept to work with such a system.

Two experienced air traffic controllers from Naples Tower Control participated in the evaluation. However, due to safety reasons, i.e. in order to avoid interference with their work, the controllers were only ask to observe the visualization capabilities of the AR system and to express their considerations on it; therefore, no direct interaction with the system was required from controllers.

The setting for the validation included Naples Tower Control.

The "identification" scenario was used as a baseline for running the demonstrations. This scenario is suitable for demonstrating the main capabilities of the AR system in terms, such as the ability to provide identification labels linked to the real airplanes/vehicles and to contextually provide additional information related to a specific aircraft (e.g. speed, direction, etc.).

The AR controller working position consisted in a standard laptop PC, displaying the AR HMI on a standard monitor.

The AR AD4 system consisted of the following hardware components:

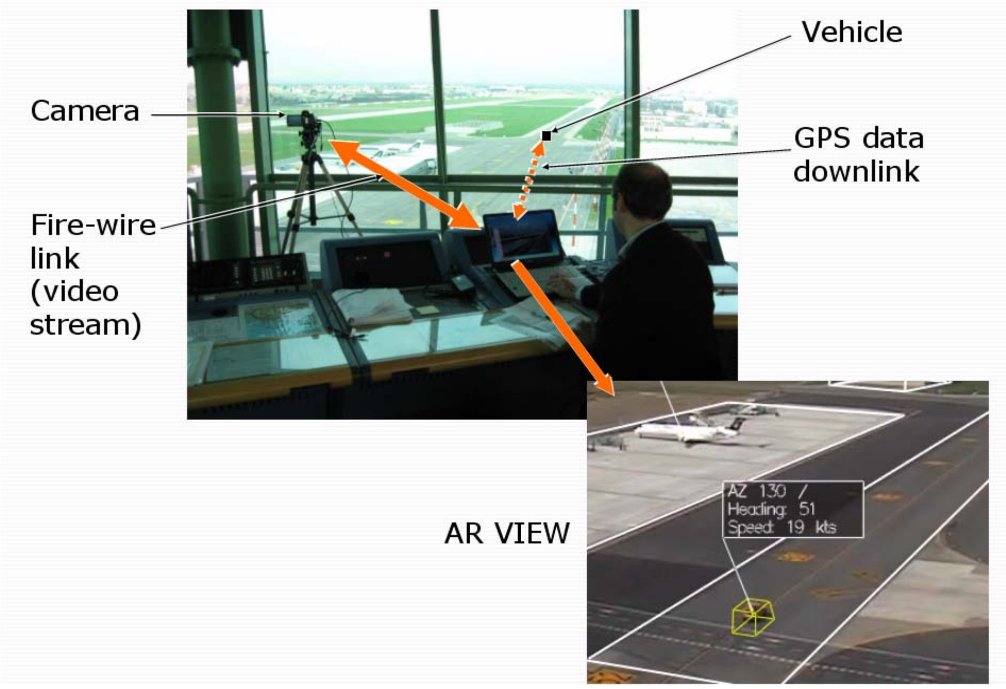
(xiv) an AR workstation, consisting in a laptop PC, showing the AR HMI visualization window as well as other GUI control panels for the control of the visual settings and the running system;

(xv) a Digital Video Camera installed at a fixed position inside the control tower, looking at R24 threshold (North-East direction) through the tower windows; the camera was connected to the AR workstation via a Firewire connection cable;

(xvi) an experimental vehicle authorized to run on the airdrome surface, according to instructions provided by the ground and tower controllers;

(xvii) an EGNOS-enabled GPS receiver installed onboard the experimental vehicle, used for position, heading and speed tracking;

(xviii) a wireless + ADSL network connection from the GPS receiver to the AR workstation.



3 DISSEMINATION AND USE

3.1 DISSEMINATION OF KNOWLEDGE

Dissemination and exploitation activities have been considered of vital importance to the project, in order to ensure that the AD4 project results find their way to the market.

In principle, the dissemination of project results will rely on the usual mechanisms for publicising scientific research. That is, the partners will place little or no restrictions on the availability of the results (beyond respecting the usual commercial confidentiality), will provide the documentation to relevant scientific libraries and establishments and publish papers in relevant journals and conference proceedings. The use of e-mail and Internet will be considered to maximise the speed and effectiveness of the dissemination.

The impact of AD4 will be enhanced by a dissemination strategy targeted towards ATM research community and relevant institutions. If research community/institutions are fully aware of what the project achieved and what the impact on the air traffic management is likely to be in the future, then they will be supportive of the actions needed to ensure full operational implementation.

With reference to exploitation, industrial partners have plans to exploit the AD4 results directly in the field of application of the AD4 technology, that is design, development and deployment of information systems in the area of main business, aerospace.

The Exploitation Plan will take into account industrial perspectives identified during the project lifecycle based on the evaluation and validation of the results achieved in terms of:

- technical feasibility with respect to the operational requirements
- effectiveness of the proposed solutions
- overall performance of the emerging technologies.

Development of the plan for the use and dissemination of the knowledge produced, feasibility studies for creation of spin-offs, "take-up" activities to promote the early or broad application of state-of-the-art technologies will all form an integral part of AD4.

Finally, the European Commission provides a further opportunity for dissemination of project results and eventual exploitation by third parties via CORDIS and the Innovation Relay Centres Network [http://cordis.europa.eu.int].

Exploitation and Dissemination activities are carefully planned for the AD4 project. In particular activities such as:

- Build a traditional Website, helping to distribute up-do-date information both to users as well as to the Commission
- Held two different Workshops to disseminate, publish and invite relevant actors of the field.
- Organise live-demonstrations to disseminate the AD4 technology
- Publication of papers over the Internet, publication through traditionally paper-based channels, presentation of the results to appropriate for a, such as R&D Centres and Academic communities. Preparation of the Technological and implementation Plan.

Over the two years of the AD4 project, members of the consortium have published 20 articles in a variety of scientific and industry outlets, developed and maintained a project website; organised and participated in three AD4 specific workshops, exhibited and demonstrated the AD4 D3 system in a number of trade conferences and industry-specific events; and have also published a contribution to the OMG Standards on CORBA Components.

The publications can be broadly grouped into the following themes that parallel the areas of work undertaken by the AD4 Consortium. The publications generally describe the key innovative outcomes of the project, including the real-time integration of the AD4 platform with distributed ATC simulation platforms, the MDA tool chain, the Open PMF-based secure middleware, the augmented reality applications in the control tower, and the Future Flight Concepts.

A project website was developed and maintained by the project coordinator, and may be accessed at http://www.ad4-project.com/. This website has two main sections: a public site presenting brief information about the project, and a private, password-protected section containing all AD4 official reports and relevant resources. Members of the consortium have also prepared videos for demonstrating various unique innovations that have emerged from the project, such as the use of augmented reality in the airport control tower. In addition, the AD4 project was featured on the EURONEWS channel in both English and Italian. A copy of that broadcast is also available at the project website. A number of posters were also prepared for presentation at conferences and workshops and are available on the website.

Partners of the Consortium have also hosted exhibition stands at various conferences and trade-shows. At these exhibition stands, the system was presented and demonstrated. Attendees at these events could also interact with the system to experience the AD4 visualisation and interaction. Specifically the exhibitions in the second part of the project are listed below.

- CER 2005, Brussels, 14-15 November 2005
- EEC INO Workshop, Bretigny-Sur-Orge, Paris, 6-8 December 2005
- Aeronautics Days 2006, Vienna, 19-21 June 2006
- EEC INO Workshop, Bretigny-Sur-Orge, Paris, 5-7 December 2006
- ATC Maastricht, Maastricht, 13-15 February 2007

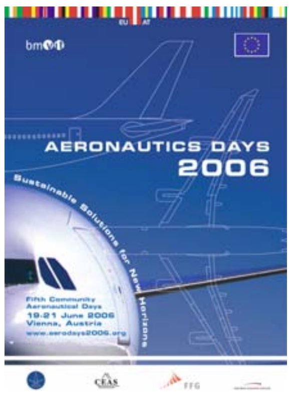
AD4 attended the Communicating **European Research 2005** (CER 2005) that took place in Brussels on 14-15 November 2005. CER is the most important event dedicated to the dissemination of the European Research. Throughout the event, latest research results and current scientific activities were presented to the media in press conferences and media briefings. A huge exhibition featured selected research initiatives as well as the communication strategies of research organizations. After a call for participation, AD4 was selected to participate among a huge set of competing projects, demonstrating the value of the first year results.

AD4 was hosted in the EC projects section of the exhibition with a stand dedicated to it and equipped with a demonstration system and posters illustrating the project. AD4 kept the attention of the visitors demonstrating its capabilities of visualizing and navigating a 3D representation of the airspace. Positive feedback came from people involved in the ATM field. Furthermore we were interviewed by the **EuroNews** satellite television (http://www.euronews.net) as well as by other media channels. A video clip with the interview is available in the Hi-Tech section of the EuroNews web site at the following address http://www.euronews.net/create_html.php?lng=1&page=hitech

AD4 was also present at the **4th EUROCONTROL Innovative Research Workshop & Exhibition** that took place on December 6-8, 2005, at the EUROCONTROL Experimental Centre, Bretigny-sur-Orge, France. The workshop is becoming a major and recognized event in Europe. In 2004, more than 150 external visitors, representing various sectors of the air transport industry in over 20 nations, attended the two-day workshop. The AD4 project was presented during the conference and at the exhibition area.

A paper illustrating the main characteristics of the AD4 project was submitted to be inserted into the Workshop proceedings and presented during the conference. The INO workshop gave the AD4 Consortium the opportunity to present concepts and ideas of the AD4 project to people involved in research activities in the ATM field. A prototype of the system was demonstrated in the exhibition area of the workshop, receiving a very interesting feedback from the visitors of the stand.

AD4 was present at the **Aeronautics Days 2006** event that took place on June 19 – 21, 2006, in Vienna, Austria (http://www.aerodays2006.org).



A prototype of the system was demonstrated in the exhibition area, receiving a very positive feedback from the visitors of the stand. The stand was composed of one graphical workstation equipped with 24 inches aspect monitors to display 3D representations of the Approach and Airdrome sectors. A connection to a server machine, equipped with the ATRES simulation platform, provided air traffic samples and flights data.

Visual impact of the presentation was emphasised by using a wider field-of-view allowed by the use of two 24' wide aspect monitors.

A **parallel session** was dedicate to the AD4 project during the **5th EUROCONTROL Innovative Research Workshop & Exhibition**, held at the EEC in Bretigny-Sur-Orge, just outside Paris, on 5 Dec 2006. Each partner in the Consortium presented (either individually or jointly) papers that reported on key aspects and achievements of their work. These papers were published in the EEC INO Workshop Proceedings and have been referred to earlier under section on 'Publications'. For convenience, the papers were also compiled separately as "Visualisation and Distributed System Technologies: The AD4 Approach. Innovative Research 2006, Parallel Event". In addition to members of the consortium attending and presenting at this parallel

workshop at the EEC, the parallel event also attracted participation from researchers at the University of Linkoping, the EEC itself, and Mitre Corporation and Emory Riddle University in the US.
AD4 was also hosted at the exhibition of the EEC INO Workshop that took place on December 5-7, 2006 in Bretigny-Sur-Orge, Paris.
The following demonstrators were presented

- The AD4 integrated system for 3D/4D visualization of Approach and Airport Environment scenarios
- The Augmented Reality Proof of Concept in the Airport Environment
- The Future Flight Concepts in the Integration of 2D/3D Displays
- The MDA Tool Chain and Security demonstrators

The **first workshop** of the AD4 project, promoted to involve major players of the field of ATM and key users, to endorse the activities of the project, helping the dissemination towards the user community and the public awareness was appointed at Rome CRAV of Ciampino the 5th of October 2005. Some of the registered attendees at the workshop were external to the Consortium and included representatives from the Italian Space Agency and the EUROCONTROL Experimental Centre in Paris. In fact, the Workshop has also led to opportunities to meet with EUROCONTROL personnel, discussing AD4 in relation to research into 3D ATC interfaces at University of Linkoping, and an invitation to attend the EUROCONTROL Innovation Workshop in December 2005.
A real mock-up of the targeted AD4 system, together with the explanation of relevant concepts by means of oral presentations for each relevant activity and the support of posters, was presented at the workshop.
It was attended by a number of air traffic controllers from Ciampino ACC, as they became available and the collection of impressions from participants and controllers were used to improve the results of the key activities and in particular to stimulate feedback from controllers. Specifically, a small feedback session on the AD4 user interface was also held with five off-duty air traffic controllers from Ciampino ACC.

The **final workshop** of the AD4 project, promoted to disseminate result of the project to major players of ATM field and key users, took place at the ENAV Area Control Centre (ACC) at Ciampino on 26th and 27th February 2007. This workshop followed an early one, which took place during October 2005, and its purpose was publicised and demonstrate the work done, the results achieved and the learning resulting from the two years project. It also possible to say that this represented a formal event which marked the end of the project.
NEXT with the support by ENAV organised the workshop. The themes were developed and each partner contributed a presentation or part of a presentation. Invites were sent to key personnel in the domain and the conference facilities booked at the CRAV (Centro Regionale Assistenza al Volo) centre at Ciampino Airport in Italy. The presentations were viewed and standardised, and each partner contributed parts as required. The workshop hall was split into two parts the presentation room and a demonstration room for the D-Cube demonstration by NEXT. The demonstrator was staffed by NEXT personnel for the duration of the workshop

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