Spatial Augmented Reality Support for Design of Complex Physical Environments

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Abstract— *Effective designs rarely emerge from good structural design or aesthetics alone. It is more often the result of the end product's overall design integrity. Added to this, design is inherently an interdisciplinary collaborative activity. With this in mind, today's tools are not powerful enough to design complex physical environments, such as command control centers or hospital operating theaters. This paper presents the concept of employing projector-based augmented reality techniques to enhance interdisciplinary design processes.*

Keywords-Design; Spatial Augmented Reality; Intense Collaboration; Interdisciplinary Design

I. Introduction

No generally accepted definition of "design" exists, however design in its broadest sense can refer to a plan for the creation of an object, interior environment or urban landscape. With such a broad definition, there is no common language or unifying body for interdisciplinary design. This has encouraged the development of different approaches toward the design process. Design at its most fundamental however, normally requires the consideration of how to make something useful, usable, desirable, producible, and well differentiated. A design process will normally involve problem analysis, problem research, conceptual development, concept modeling, prototyping, interactive tuning and final documentation.

Design is often viewed as a more rigorous form of art, or art with a clearly defined purpose, normally to meet the needs of someone other than the design's creator. Design and engineering on the other hand appear at different ends of an overlapping spectrum, one end of the spectrum being user focused and the other technology focused. The overlap depends on the disciplines in question. This paper is concerned with the design of complex physical environments, such as command centers, hospital operating theatres, and planning facilities. Tasks in these rooms are characterized by intense collaboration and sometimes make use of pervasive computing technologies. The complexities of these environments justify an interdisciplinary design approach.

The design process for these environments requires consultation during the entire process with different stakeholders, such as clients, designers, engineers, managers, end users and maintainers. To gain a common view of the current state of a design, all the stakeholders evaluate a set of artifacts, images, drawings, and physical prototypes. The key problem with many of these artifacts is that the design cannot be easily modify during one of these reviews. This is especially true for physical prototypes. This paper investigates a more expressive and flexible design mediums for these artifacts. To this end, we believe Spatial Augmented Reality [1] is a useful technology that can span the gap between design in the virtual space (CAD, 3D images, and animations) and the physical space (physical prototypes and 3D printing).

Spatial Augmented Reality (SAR) is a set of technologies that allow physical objects to be augmented with computer generated images. This approach can provide a number of advantages for the presentation of ideas including:

1) the physical object's attributes may be altered (color or texture),
2) fine detail can be added,
3) user interactions can be simulated, and
4) users can physically touch augmented objects.

Digital projectors are embedded into the environment and project onto physical objects. These objects can be tracked, allowing the projections to be updated as the objects move. This allows users to be able to physically touch augmented objects, and natural depth cues are preserved. SAR also naturally accommodates multiple users, supporting collaborative tasks. Most SAR research is based on the concept of shader lamps [2], which describes how the appearance of physical objects can be changed through the use of calibrated projectors. This was extended to allow users to digitally paint onto objects[3] with a stylus. SAR has been used for entertainment purposes, including animated cartoon dioramas [4] and tabletop games [5].

The physical nature of SAR makes it suited to industrial design tasks. WARP [6] allows designers to preview different materials on rapid prototype design mockups. Laser projectors have been used with SAR in industrial processes, including marking weld points [7], and interactively programming robot arm paths [8]. Our own work has used SAR for digitally airbrushing onto physical objects [9], aiding prototype creation with augmented foam sculpting [10], and to act as virtual controls on physical control panels [11].

This paper begins with a description of the issues for designing complex physical environments and those for interdisciplinary design in general. These discussions provide a framework to explore the benefits of applying SAR technology in the development of future design tools. These benefits are then outlined in detail. An illustrative scenario that reflects some of our current work will then explore the potential benefits in using SAR within the context of complex design problems. Finally, because SAR technologies may be applied to tools for many different phases of the design process, an in depth investigation of the life cycle of design environments is then presented.

II. Background

This section discusses some of the challenges of designing complex physical environments that support teams engaged in intense collaborative activities. We begin by providing an overview of research that others and we have conducted in applying pervasive computing technologies in the design of these environments. This sets the scene for discussing some characteristics and challenges of these types of complex physical environments.

A. *Challenges of Design*

There is a significant body of work that has been undertaken to investigate how pervasive (or ubiquitous) computing approaches can be used to enhance physical collaborative workplaces, such as meeting rooms. Examples of research initiatives in this area include Stanford's Interactive Workspaces [12], MIT's Intelligent Room [13], GMD's i-Land [14], and Active Spaces at the University of Illinois Urbana Cahampaign (UIUC) [15]. Much of the focus has been on the design and development of the underlying operating environments and infrastructure required for coordinating the devices, displays and applications within a workplace. Work has been done on the design of new furnishings such as the CommChair and InteracTable [16] and new types of interactive interfaces such as the extensive use of gestures and speech [17]. Others have focused on how these types of environments can be designed to support specific types of activities. For example, Mark [18] conducted studies to assess how these types of environments might support collocated teams engaged in the design of space missions at NASA's Jet Propulsion Laboratory.

Our research in this area has evolved through several projects and phases of research and development activity over the past decade covering foundational research though to deployment and evaluation [19]. The particular focus of the work has been on how pervasive computing approaches could be used to enhance the effectiveness of collocated and geographically distributed teams engaged in intense collaborative activities [20]. This includes critical planning activities being undertaken in support of Defense and National Security.

One of the outcomes of the research was an approach called LiveSpaces, which has been used for the design and development of several Intense Collaboration Environments in Australia, Canada, and the USA. LiveSpaces provides a pervasive computing infrastructure, called the LiveSpaces Operating Environment (LOE) [21, 22], which allows for the integration and orchestration of a range of workspace services, applications, and technologies. This approach supports the seamless integration of several participating LiveSpaces. A host of workspace services and applications have been designed and developed. For example, LiveSpaces has services that allow automated setup and orchestration for specific activities [23]; the use of speech control, capture and transcription [24]; new applications such as Ignite which provides a common interface for interacting with the environment. Investigations have also been done into how approaches such as Augmented Reality can be employed to support visualization, tracking, and user experience [25]. In addition to the technological aspects, significant design effort went into the development of new furnishings such as the use of configurable desktops with writable surfaces, workspace colors and materials, and methods for allowing users to physically reconfigure the position of displays and whiteboards.

The LiveSpaces work identified many lessons and challenges for the design of complex physical environments such as Air Traffic Control centers, shipboard command and control facilities, and hospital operating theatres. The challenges of integrating and supporting a wide range of technological support is in itself complex. However, the socio-technical challenges of supporting teams engaged in intense collaborative activities in these environments poses the major problem for those responsible for their design and deployment. These types of activities are characterized by "the level and frequency of interactions needed for initiating and sustaining joint action and mutual awareness of the members of the team, the flux of activities in teamwork, the evolving work-object, and the context of the collaboration situation" [26].

These types of capabilities are typically expensive, have a long lifecycle and involve a variety of stakeholders over a significant period of time. The tasks performed in these environments are often unprecedented and require the environment to be highly configurable and adaptive so that they can be tailored for the specific situation. In many instances, this may require the incorporation of new devices and layout changes. As such, design is ongoing throughout the lifecycle of the "product".

The disciplines involved in the design of these facilities is broader than that generally considered for a more typical product design where a need is identified through marketing and sales, industrial designers consider various aspects of a typical user community, technical disciplines then design a product to meet these requirements, and then product is produced and sold to clients. In our case, there were typically several stakeholders and disciplines involved collectively and collaboratively in the initial, and ongoing, design of each of the LiveSpaces deployments. These included systems and software engineers, project managers, researchers, tradesmen, and especially the end user community. Each discipline has different backgrounds and goals that needed to be accommodated and each group thought about the design from a particular point of view. One of the major problems was that there was no common design medium to accommodate each of the viewpoints, provide linkages to specific design products, and to capture design tradeoffs and considerations.

III. Interdisplinary Design

An award-winning design rarely emerges from good mechanical design or aesthetics alone. More often, it is the result of a product or building's overall design integrity, or the way in which form and function are packaged to convey a consistent message, with common themes holding true across various industry sectors and product types.

Design is inherently a collaborative activity, involving internal and external interdisciplinary groups and stakeholders. Internally they may include industrial design, engineering, marketing, manufacturing, sales & service and externally they may include partners such as customers, technology suppliers, material/component suppliers, co-development partners, subcontractors, contract manufacturers, sales distributors and end users. Very few organizations posses all the skills and resources required to develop technologically complex products themselves and increasingly, firms are tending to concentrate on their core competencies and elect to collaborate with others, to gain access to complementary skills and resources.

Traditionally, many companies have had a strong functional design process orientation, with projects handed-off from one department to the next in a linear domain approach. More recently however, companies have adopted a multidisciplinary concurrent approach where a core interdisciplinary team is responsible for taking the project from concept through to delivery. The core team contains representatives of the most important functional groups, and is augmented from time to time with representatives from other areas as required, including external partners where appropriate. Decision making control however has tended to lie with the group driving the particular design technology. As computer aided design and engineering tools have become more technically complex and specialized, decision-making has tended to become aligned with this knowledge domain, excluding and marginalizing the other disciplines from the decision process. We see this failure of the decision making process as a critical point require more sophisticated and easy to use tools to support all stakeholders in this complex process.

IV. SAR Capabilities

We have an ongoing collaboration between industrial partners, designers from the School of Art, Architecture and Design, and computer scientist from the School of Computer and Information Science at the University of South Australia. We are investigating the use of SAR in the design process across a range of final artifacts, command and control centers, hospital operating theatres, home appliances, automotive manufacturing, electronics manufacturing, and interior design. In particular we are working with a global electronics manufacturer, a hospital and a global architecture to achieve this. Our collaborative efforts are focused on developing tools to aid in the iterative aspects of the physical design, whilst providing interactive functionality early in the detail design process. Presently, we have a first cut design of the prototyping system along with a significant infrastructure (SAR laboratory containing 40 projectors along with tracking technologies).

To support the process of SAR interactive rapid prototyping, there are three main artifacts to be considered:

1) The prototypes themselves that designers, clients, and stakeholders can interact with and make considered judgments concerning the design;
2) The technology infrastructure to support the development and presentation of the SAR prototypes; and
3) A complete toolset to allow designers to create interactive SAR prototypes.

What we find interesting about the use of SAR as a design medium is SAR's ability to convey concepts to many stakeholders in the design process at once. The fact everyone is viewing a design concept as a full physical 3D object with a one-to-one size, allows for an easily digestible form of presentation. The users are able to physically touch the prototype design, and this passive haptic feedback provides a more complete sense of size, shape and depth. This more natural mode of demonstrating the design allows each of stakeholders an equal footing in the decision making process. We refer to this as "*design democratization*". The detail of the design is projected onto the physical substrate and can be easily modified, and thus allows for a very flexible medium to communicate many different ideas. The technology is able to operate through the many stages of the design process, and is therefore a pervasive technology for design.

There are several benefits of using SAR for design. Firstly, a projected design can be viewed by multiple people at the same time. This enables simultaneous collaborative design between several people with different views on the requirements. Another advantage of SAR is that no additional hardware is required to view the augmented prototype. Other AR display technologies, such as head mounted or handheld displays, require the user to look at a screen for a view of the AR world which is inherently solitary which works against large scale design. Users of the SAR system can freely interact with the prototypes while being unencumbered by additional hardware that is required for many other augmented/virtual reality approaches.

V. Design Scenario

At present the life cycle of a complex physical environment is to specify the requirements, consult with stakeholders, design the space and finally implement the space. The final design is implemented and the users begin using it. Between consultation and implementation many decisions are made that can invalidate the input from the stakeholders. This leads to misunderstandings in the final implementation. The process then switches to maintenance where at some point in the future the space may be updated, which requires a second design to be done based on the shell of the existing space. Again stakeholders are consulted early in the process and the final complex physical environment is then designed and refurbished. The final phase of the life cycle is that the space is removed at the end of its useful life.

For example, a large hospital wishes to upgrade its hospital wards and operating theaters. They intend the fit out to meet the needs of all users for the next 20 years so it is vital the fit out is right the first time. In order to ensure all users are consulted and can meaningfully contribute to the design of the new spaces they use the Immersive Design laboratory as a forum for participatory design

Imagine three experienced nurses, working with a designer. In the designers hand is a blank white board, about A3 in size, on her finger is a small orange thimble.

They enter the space, a large room with lots of white boxes and other shapes and a hospital bed. White walls have been erected to enclose spaces the same size as the room to be refitted. These walls can be easily moved to create a room of new dimensions when required. At first look it all appears quite plain and nondescript, then the lights come down.

The white walls are digitally draped with color, light switches, power points, skirting boards, paintings, windows and doors. The board the designer is holding is covered in icons and menus.

One of the nurses notices that one of the doors is too far to the left. The designer touches the menu on the A3 tablet then points at the door, the edges of the door glow, she gestures with her hand and the door moves to the right. Once they are happy with the doors new location the designer taps the menu again and saves the configuration, this also updates the master computer model for the room with an annotation of the time and author of the change.

The first question is how to arrange the services built into the wall across the head of the bed. These need to be designed and specified properly now, if there are any problems with the location of these services it will be very expensive to fix once 20 rooms have been fitted out.

First a long white box is picked up and attached to the wall with magnets; the box is the approximate size of the services board. Once the designer touches the box the system recognizes it and paints it with rows of question marks. As the designer moves the box the projectors 'chase' it around the room, so no matter where the box is its surfaces have the same image projected on them. The computer model of the room 'knows' where it is in the room at all times. The question marks on the surface tell the designer no features have been assigned to the object yet. The designer taps the menu tablet and points to the box, on the box appear a series of images of the head board services, oxygen outlets, buttons, switch sets, alarm lights and so on. The designer then asks "where should they be? ".

Now the nurses put on their thimbles and they move the items around on the box to find a usable arrangement. Each time they make a change they can stand back and see what their proposed design looks like. They move around the space discussing various patient treatment scenarios and reaching for the switches on the headboard. Sometimes they are in the right place, sometimes not. If the arrangement doesn't work they move the items around then do another walk through to see if the placement has made an improvement. The services box can be moved around, up and down and side to side, each time the surface of the box stays the same.

Sometimes as they move an item a red flag appear next to it with text stating that the item may not be able to be placed there because it conflicts with other services or preexisting structures. The computer model incorporates intelligent systems that checks that the proposed locations are technically achievable and meet standards.

After a while they are satisfied with the arrangement of the headboard. In the Immersive Design laboratory the nurses were able to experience the design in the space at full scale. They could check for reach heights and access and see the arrangement from lots of different points of view. They could experiment with lots of different arrangements there and then and trial them immediately.

Now this arrangement is complete the designer taps the menu again and the arrangement is saved for future reference and design documentation. It includes a note of the date and time and who was present at the consultation. The designer records a short verbal summary of the reasons for the design; this is attached to this assembly in the computer model as a sound file for future reference.

Next the group will discuss the arrangements of some cupboards with a sink along one of the walls. The designer touches one of the boxes, it illuminates with question marks. She paints it with blue, silver handles and a white bench top. Each time she calls up surface finishes a menu appears with manufacturer's product listing including colors, textures, environmental footprint, cleaning and maintenance requirements and costs.

She moves the box/cabinet to the wall and asks the nurses for their thoughts. First they comment it is too short, so she pulls the top and the box telescopes up until they find a height that the nurses agree is suitable. At the same time the system could be consulting a database of good design principles to guide the users on standard practices such as ergonomics. Each time the box size is changed the projection of the surfaces follow the new areas. Then they think the cabinet should be wider so the designer pushes another box beside it. Once it touches the first box it is painted with the surfaces from the first box. The nurses try various locations along the wall, and configurations of doors and drawers, and surface finishes. To make cabinet doors wider the designer touches the surface of the cabinet on the join line and drags it to a new position. Each time a door is specified the opening arc of the door is painted on the floor to check for clashes with other elements in the room. In one case the opening arc of the cupboard door clashed with the bathroom door, a flashing red light on the floor draws attention to the clash so the users can see the conflict and choose what to do.

This process continues including changing the location of light switches and PowerPoint's, the window treatments, even the location and types of art on the walls. Eventually all of the cabinetry, controls and services have been discussed, evaluated and experienced in real space. The nurses have been able to work in an environment that provides real three-dimensional experience and feedback while allowing the flexibility of a computer generated space. They could try out and evaluate lots of different arrangements, sizes and finishes in a short time. The result is a What-You–See-Is-What-You-Get experience for interior spaces that cannot be replicated via drawings or looking at models on a computer screen.

However, nurses are of course not the only stakeholders. In the design of the hospital theatre there are a variety of experts who will be using the space will be significant. The variation and number of stakeholders leads to difficult decisions being made about who gets a say in the design. Normally the contributing members are limited to the designers, the managers and possibly a select group of surgeons. Whilst there are many more stakeholders such as the original design team members, architects, engineers and medical facilities experts, to the other end-users, including other surgeons, anesthetists, theatre staff and cleaners, each domain expert brings a different perspective on the role of the room within their field of expertise. For example cleaners which are very rarely consulted have very specific needs around the arrangement of facilities to optimize both the time and quality of cleaning tasks. The design team can quite easily omit this information in design and concentrate on the needs of the surgeons leaving a work place that costs considerably more to be adequately maintained. Whilst it is possible to rely on established design and work solutions from previous examples and imitate them, the reality of 21st century medical practice is that the facilities and the methods of using them have developed at a faster rate than theatres designed decades ago.

The optimum method for ensuring that a complex environment such as this operating theatre, or any environment that relies on the multiple areas of expertise, is to ensure that the consultation, design and review process is as achievable. Usually, this is done by producing plans/sketches and/or digital models of the space but it is a reality of these types of processes that clients and end-users have only a partial understanding of what they are being shown. It is hard for the stakeholders to mentally place themselves in the final design based on drawn two-dimensional diagram or a on screen picture. This leads to misconceptions between the faulty interpretation and the final reality.

If a fully immersive SAR environment could be supplied for the theatre that located all the necessary facilities in place, but permitted them to be adjusted 'live' as design consultants and end-users moved through the room. Inexpensive mockups that are physical the correct enclosing volume is rendered with detail from the SAR projectors. This provides a much more natural method for a stakeholder to evaluated the current design, as they view the design in the same manner as the end product. This provides an additional tool to complement the existing suite of design tools and visualization techniques. The ability to touch surfaces, measure distances and 'role-play' the procedures the room is intended for would greatly enhance the degree to which all parties would understand the procedural qualities of the room. Thus the design team could include all the stakeholders at the same time, which could discuss impacts of designs insitu. This would eliminate the common problem where designers take input from one stakeholder then change it when another stakeholder has conflicting requirements. In this scenario too, the ability to capture these discussions provide an invaluable resource for documenting the process and is provided as a side effect of the process. Finally, the capability of exporting this information back to all design team members would ensure consistency of reporting of information.

VI. Life Cycle of Design Environments

With the advantages of a Spatial Augmented Reality Studio, the lifecycle of a building space can be modified to better utilize the technologies available. Unlike the current process, which virtually abandons the design documents, after the space has been designed, a SAR design studio can support the space through its working life. Figure 1 shows how the SAR Design studio can interact with the spaces it aided in the design. The SAR studio can act as an interactive design medium that in addition to aiding in the design can also;

- *Collect* experience from the space (in order to improve future development). For example issues may be found in the arrangement of the space that cannot be fixed but should be taken into account in future iterations of the space design.
- *Act* as a simulation of the environment to try scenarios. For instance in the case of an operating theatre once in use the operating theatre would be highly utilized and any planned changes would have to be done offline. The SAR design studio could be used as an interactive design schematic in which users could immersively pre-model scenarios before moving into the real environment.
- *Test* new capabilities. The SAR design space can be setup to try out new capabilities in the space before rolling out to the real environment. Staff can try out new capabilities to see if they are workable in the real environment. For example the introduction of a new method of air traffic control may necessitate the introduction of new screens or equipment for the controllers. These new pieces of equipment could be simulated in the SAR design studio and then human factors testing done to ensure that the new capability is safe for rolling out in the real live environment where lives are at stake.
- *Finally* at the end of life for a space the SAR Design Studios interactive design schematic can be used for both for planning decommissioning and also the

sequencing of the design an commissioning of the new space.

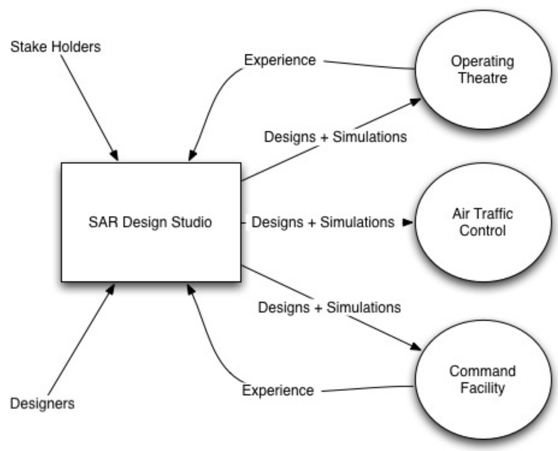

Figure 1: Life Cycle of Spaces and SAR Studio

The SAR design studio can be thought of as an interactive design schematic that can be used to help design the space, maintain the space and help decommission the space and could be considered a full life cycle support tool.

VII. Conclusion

This paper presents the use of Spatial Augmented Reality Technology as a means for helping in the inter-displinary design of complex physical environments. The major issues for interdisciplinary designing and that for complex physical environments are explored. The benefits of applying SAR technology in the development of future design tools are defined. These benefits were outlined in detail with examples. A case study was presented to highlight the benefits in context of a large design problem. Because SAR technologies may be applied to tools for many different phases of the design process, an in depth investigation of the life cycle of design environments was presented.

VIII. References

1. Bimber, O. and R. Raskar, Spatial Augmented Reality: Merging Real and Virtual Worlds2005, Wellesley: A K Peters.
2. Raskar, R., et al. Shader Lamps: Animating Real Objects With Image-Based Illumination. in Rendering Techniques 2001: Proceedings of the Eurographics. 2001.
3. Bandyopadhyay, D., R. Raskar, and H. Fuchs. Dynamic Shader Lamps: Painting on Movable Objects. in IEEE and ACM International Symposium on Mixed and Augmented Reality. 2001.
4. Raskar, R., R. Ziegler, and T. Willwacher. Cartoon dioramas in motion. in NPAR '02: Proceedings of the 2nd international symposium on Non-photorealistic animation and rendering. 2002. New York, NY, USA: ACM.
5. Jones, B.R., et al. Build Your World and Play In It: Interacting with Surface Particles on Complex Objects. 2010. Seoul, Korea.
6. Verlinden, J., et al., Development of a flexible augmented prototyping system. Journal of WSCG, 2003.
7. Schwerdtfeger, B., et al. Using laser projectors for augmented reality. in Proceedings of the 2008 ACM symposium on Virtual reality software and technology. 2008. Bordeaux, France: ACM.
8. Zaeh, M.F. and W. Vogl. Interactive laser-projection for programming industrial robots. in Mixed and Augmented Reality, 2006. ISMAR 2006. IEEE/ACM International Symposium on. 2006.
9. Marner, M.R., B.H. Thomas, and C. Sandor. Physical-Virtual Tools for Spatial Augmented Reality User Interfaces. in International Symposium on Mixed and Augmented Reality. 2009. Orlando, Florida.
10. Marner, M.R. and B.H. Thomas. Augmented Foam Sculpting for Capturing 3D Models. in IEEE Symposium on 3D User Interfaces. 2010. Waltham Massachusetts, USA.
11. Porter, S.R., et al. Validating Spatial Augmented Reality for Interactive Rapid Prototyping. in proceedings of the 9th IEEE International Symposium on Mixed and Augmented Reality. 2010. Seoul, Korea.
12. Johanson, B., A. Fox, and T. Winograd, The Interactive Workspaces Project: Experiences with Ubiquitous Computing Rooms, in IEEE Pervasive Computing Special Issue on Overviews of Real-World Ubiquitous Computing Environments2002.
13. Brooks, R.A., M. Coen, D. Dang, J. DeBonet, J. Kramer, T. Lozano-Perez, J. Mellor, P. Pook, C. Stauffer, L. Stein, M. Torrance and M. Wessler, The Intelligent Room Project, in Proceedings of the Second International Cognitive Technology Conference (CT'97)1997: Aizu Japan.
14. Streitz, N. and et.al, i-LAND: An interactive Landscape for Creativity and Innovation, in ACM Conference on Human Factors in Computing Systems1999, ACM Press: Pittsburgh, PA, USA.
15. Cerqueira, R., Hess, Chr. K., Roman, M., Campbell, R.H., Gaia: A Development Infrastructure for Active Spaces., in Ubitools Workshop at Ubicomp 20012001: Atlanta, GA.
16. Streitz, N.A., et al., Roomware: Towards the Next Generation of Human-Computer Interaction based on an Integrated Design of Real and Virtual Worlds. Human-Computer Interaction in the New Millenium. J. Carroll (ED), 2001: p. 553-578.
17. Coen, M., et al., A Context Sensitive Natural Language Modality for the Intelligent Room, in In Proceedings of MANSE'991999: Dublin, Ireland.
18. Mark, G., Extreme Collaboration. Communications of the ACM. 2002. 45(4).
19. Vernik, R., Intense Collaboration Environments. The International C2 Journal. Special issue on Intense Collaboration, 2010.
20. Blackburn, B. D, and V. R, Evaluating Procedural Aspects of Intense Collaboration, in The Third Nordic Conference on Human-Computer Interaction2004: Tampere, Finland.
21. LOE, Livespace Software, in Sourceforge Site2010.
22. Phillips, M., Livespaces Technical Overview, 2008, Defence Science & Technology Organisation.
23. Vernik, M., S. Johnson, and R. Vernik, e-Ghosts: leaving virtual footprints in ubiquitous workspaces, in Australasian User Interface Conference2004: Dunedin New Zealand.
24. Zschorn, A., et al., Transcription of multiple speakers using speaker dependent speech recognition, 2003, Defence Science Technology Organization.
25. Slay, H., B. Thomas, and R. Vernik. Using ARToolkit for Passive Tracking and Presentation in Ubiquitous Workspaces. in The Second IEEE International Augmented Reality Toolkit Workshop. 2004. Waseda University, Japan.
26. Kumar, K., vanFenema, P.C. and M. Von Glinow, Intense collaboration in distributed work teams: Evolving patterns of dependencies and coordination. Managing Multinational Teams:. Global Perspectives Advances in International Management, 2005. 18: p. 127-154.